POTENTIAL PATHWAYS OF ECONOMIC IMPACT FOR THE ATP DIGITAL VIDEO PROGRAM

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The Principal Investigator on the project was David Burress, an Associate Scientist and Research Economist at IPPBR, who also was lead author for this report. Additional economic analysis and drafting were provided by Patricia Oslund, Research Economist at IPPBR, and Joshua Rosenbloom, Associate Professor of Economics. Other members of the research team included Susan Mercer, Program Assistant at IPPBR, who served as project manager; John Gauch, Associate Professor of Electrical Engineering and Computer Science, who acted as an in-house resource person on digital video; and Daniel Cardwell, an Undergraduate Research Assistant at IPPBR. All research was performed under the general direction of Charles Krider, Director of IPPBR and Professor of Business, who provided useful comments on the draft report. Larry Hoyle, Coordinator of Information Processing and Associate Scientist, provided expertise on networking applications of digital video.

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EXECUTIVE SUMMARY

Purpose

- The report was prepared in conjunction with the Focused Program on Digital Video in Information Systems of the Advanced Technology Program (ATP), an operating unit of the National Institute of Standards and Technology (NIST), US Department of Commerce. The report provides information on the pathways or causal links that could potentially lead from activities of the Digital Video program to impacts on the U.S. Economy.

- The main goal of this report is to describe all potential pathways for U.S. economic impacts of the ATP Digital Video Program.

- The intended application of this report is to support an ongoing study of the economic impacts of the ATP DV program. It is anticipated that the study as a whole will eventually provide a definitive record of the effects of the program on the U.S. economy. In the mean time, this report may also be helpful to ATP staff charged with the administration of the Digital Video Focus Area.

- This report could also serve as a model for use in other studies of the impact of technology and R&D programs. Similar methodologies might also be applied to impact studies for other types of program evaluation.

- This report includes several different products that may be of interest to different audiences. It includes:

  - a theoretical computable general equilibrium (CGE) model of the U.S. economy, together with the sketch of a practical computational solution algorithm. This model identifies various contact points through which technology innovation can potentially affect the macro-economy, and also provides a theory of aggregation for these effects. (No models are actually implemented, because the purpose of this report is pure classification.)

  - a theory of technology impact channels or pathways, which is rooted partly in the general equilibrium model, and partly in the idea of spillovers.

  - a particular set of diagrams for describing classes of transactions and spillovers, and a resulting taxonomy of spillovers.

  - results of 21 intensive interviews with experts on particular DV technologies, with a focus on future expected economic effects and spillovers.

  - a mapping or taxonomy which describes between 500 and 1000 distinct DV technologies (depending on what is viewed as a discrete technology).

- a listing and discussion of the identified pathways of economic impact that are viewed as potentially significant for the ATP's Digital Video Program.

Approach

- Our theoretical approach has several important features:

  - "Impacts" of ATP are defined in terms of a counterfactual analysis. They consist in differences between measurements in the actual world (in which various ATP interventions occurred), and corresponding measurements in a modeled counterfactual world in which no ATP interventions occurred.

  - The assumed model of the world includes a multi-sectoral computable general equilibrium (CGE) model of the US economy. It also includes "bridge models" that bridge the gap between the micro-level activities of ATP and the relatively more aggregated CGE model.

  - The bridge models have three important features. First, bridge models are associated with individual technology innovations, or else with pairs of innovations in which one innovation influences another. Second, as proposed by Jaffe [1996], bridge models are organized around the idea of the "spillovers," i.e., side-effects or unintended consequences of a technology innovation. Third, for each spillover it is necessary to build an "attribution model," which measures the degree of causal responsibility that can be attributed to ATP for the existence of the spillover.

- The organizing principle of this report is taxonomy, or systematic classification. The report employs a number of different principles of classification.

  - The CGE model is used to enumerate all possible points of contact between spillovers and the larger economy.

  - Bridge models are classified according to the pattern of innovations and spillovers they include and the contact points they reach.

  - Spillovers are grouped into broad classes based on the economic nature of each spillover. Jaffe [1996] discussed three different classes, but based on a formal analysis we have expanded his scheme to five main classes. Our classes include two classes that have to do with reciprocal interactions (market and network spillovers), three classes that have to do with unidirectional flows (knowledge, fiscal, and material spillovers), plus a number of cross-categories. We have also defined a system of diagrams for identifying classes of economic transaction. Spillover classes are then defined formally in terms of these diagrams.

- Particular digital video technologies are enumerated and classified, drawing on an empirical analysis of digital video markets contained in Burress *et al*. [1998]. That analysis employs Lancaster's [1971] method of description of commodities as points in a space of potential characteristics. A technology innovation is defined as the introduction or quality improvement in a given technology.

- Finally, particular pathways of economic impact are categorized by the particular innovation (i.e., the introduction or improvement of a particular technology) and by the pattern and classes of spillovers it engenders. Because the theoretical space of potential pathways turns out to be extremely large, our empirical analysis is limited to spillovers whose probability of occurrence and economic importance has been judged as substantial by expert opinion.

- Our empirical data sources include searches of paper and electronic literature, and intensive interviews with digital video experts. We have also drawn heavily on the empirical analysis of digital video contained in the first report of this series [Burress *et al*, 1998].

Findings

- We are able to distinguish more than 500 individual digital video technologies (depending on level of aggregation chosen).

- Our theoretical analysis shows that the potential number of distinguishable pathways is extremely large. For example, if we assumed the following (not unreasonable) levels of disaggregation:
  200 detailed technologies
  just 1 innovation per technology (e.g., its introduction to the market)
  5 classes of spillovers
  8 types of contact point that spillovers can make with the CGE model
  knowledge spillovers between innovations are not followed for more than 1 step
  network spillovers are not followed for more than 2 steps,
  then we would have tens of millions of distinguishable pathways.

- Our empirical analysis shows that, in the case of digital video, a rather large number of pathways actually are of potential economic significance. Consequently, to carry out any meaningful discussion it is necessary to group the technologies at a high level of aggregation.

- At the most aggregated level, we distinguished four groupings of DV technologies. Consistent with the approach adopted in our previous report, the groupings are defined in terms of the general function or end use, and consist in:

  - DV Content Creation, Capture, and Display
  - DV Data Storage, Access, and Retrieval
  - Transmission and Management of DV Data Streams and Intellectual Property
  - End uses of DV Data Streams

- Empirically, potential knowledge spillovers of some importance can occur in either direction across almost all pairs of these technology groupings. For example, advances in visual pattern recognition methods could either grow out of, or have potential applications to, content creation (e.g., computer animation methods), DV access (e.g., locating images by type), DV transmission (e.g., designing compression strategies that depend on content), or end use (e.g., human-computer interface models). Moreover, there are potential knowledge spillovers to technologies entirely outside the DV area (e.g., applications of pattern recognition to complex data analysis).

- Network spillovers are likely to occur across any subset of these four groupings. At the highest level, there is a fundamental and positive network spillover in which the entire complex of DV technologies complement each other. For example, if any element in the chain from content creation through storage and transmission to end use becomes less costly, then the market for end uses is likely to expand; an expanded market is likely to lead in turn to more varieties of content being produced; and (if markets work as they should) more variety in turn means more choice and increased value received by the consumer. Moreover, there are network spillovers in relation to technologies entirely outside the DV area. For example, falling prices in microelectronics or computers leads to falling prices in DV, which may trigger renewed R&D efforts in DV. Improvements in DV, in turn, could lead to improved design and production methods in computers and microelectronics.

- Knowledge and network spillovers could also be significant among technologies within each of these four groupings. For example, the components of a transmission system work together as a network. Also, there could be knowledge spillovers between transmission protocols and methods for implementing "aware" networks that adapt themselves to equipment conditions and availability and network usage.

- Market and fiscal spillovers are much less interesting than network and knowledge spillovers, because the first two classes of spillover are both innate and ubiquitous. Every successful technology innovation will be commercialized through market transactions which produce added value for both buyer and seller -- a market spillover. Market transactions also lead to taxable events -- a fiscal spillover.

- However, the *distribution* of market and fiscal spillovers between buyers, sellers, and government is likely to be sensitive to the market structure, and especially sensitive to the degree of competition on the supply side. We find that many DV technologies are likely to be competitive in the next 5-7 years because basic information tends to be common knowledge and there is much opportunity for inventing around patents and trade secrets. That suggests that in some cases there could be underinvestment in R&D because of an anticipated inability to recapture sufficient rents on intellectual property rights.

- More generally, the potential pervasiveness of the first four kinds of spillovers suggests that underinvestment in DV-related R&D could be a widespread problem. Given the intensity of existing DV R&D efforts, this might seem counterintuitive -- however, if the expected social returns to DV R&D are sufficiently high, then it might be better if the overall level of DV R&D were even higher than it already is. Moreover, even if the general level of R&D is high enough, the level of spillovers could be especially high in particular niches, leading to uneven investment in R&D. In any case, these are empirical questions for future research. The purpose of the present report is to raise these questions, not answer them.

- If there is underinvestment in R&D, then ATP interventions could have real impacts on the timing or national location of DV innovations. This will be a major topic for future research.

- In the longer run, if the pace of technical change slows down in some of the particular technologies, then market leaders with significant market power are likely to emerge because of forces such as returns to scale (e.g., the innately low marginal cost of duplicating software) and the user's installed base of equipment and skills. In addition, as DV becomes increasingly synonymous with the whole of the entertainment industry plus the communications industry, the possibly innate tendencies of those two industries toward monopoly could come into play (if it is not restrained through anti-trust action). Major industry concentrations could create monopsony buying situations for much of the DV-related technology.

- What is most interesting about material spillovers is that relatively few of them have been identified. The production of DV-related hardware and of electricity to power DV applications will place some burden of pollution on the environment. The use of DV equipment in safety-related functions may have some positive impacts on third parties who were not part of the chain of commercial transactions.

1. INTRODUCTION

Purpose

This report is part of a research initiative entitled “Pathways to Economic Benefit for the Digital Video Program.” The Digital Video Program is a Focus Area of the Advanced Technology Program (ATP), a branch of the National Institute of Standards and Technology (NIST), which is funding this research. This research initiative is concerned not only with the potential economic impacts of digital video (or DV) in particular, but also with developing formal methods and models for other technology impact studies that may be conducted by ATP. This is the second in a series of reports on Digital Video impacts written by the Institute for Public Policy and Business Research at the University of Kansas.[1]

The first report in this series [Burress *et al*, 1998] identified markets which are likely to be significantly affected by the Digital Video Program. The present report is intended to “describe all potential pathways to U.S. economic impact.”[2] Much of this report is a theoretical effort to clarify the idea, as well as the possible varieties, of a “pathway.” Once pathways have been defined, the rest of this report provides an empirical application to the ATP Digital Video project. This report does not actually measure the size or importance of the economic effects along any given pathway -- that task will be reserved for future reports in this series. However, this report does provide some initial screening to establish which potential pathways are expected by expert opinion to be “significant,” versus those that are not.

This report includes several different products that may be of interest to various audiences. It includes:

- a theoretical general equilibrium model of the U.S. economy, together with the sketch of a practical computational solution algorithm. This model identifies various contact points through which technology innovation can potentially affect the macro-economy, and it also provides a theory of aggregation for these effects.
- a theory of technology impact channels or pathways, which is rooted partly in the general equilibrium model and partly in the idea of spillovers.
- a particular set of diagrams for describing classes of transactions and spillovers, and a resulting taxonomy of spillovers.
- results of 21 intensive interviews with experts on particular DV technologies, with a focus on future expected economic effects and spillovers.

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[1] Other reports on the same general topics are being prepared independently by the Research Triangle Institute in North Carolina.

[2] This is the goal set for Task 2 in the original RFP (ATP, 1997, p. 2).

- a mapping or taxonomy which describes between 500 and 1000 distinct DV technologies (depending on what is viewed as a discrete technology).
- a listing and description of the identified pathways of economic impact that are viewed as potentially significant for the ATP's Digital Video Program.

Theoretical approach and definitions of terms

Formal research methods generally start with language that is widely used but relatively vague and try to clarify it or make it operational. In particular, the goals of this research, as stated above, use words such as "benefits," "technology," and "pathway" that will need to be given relatively technical definitions. These definitions are determined in part by the models and methods that will be employed in the research itself.

Net benefit analysis

We identify the benefits of the digital video program with "*net* benefits," i.e., benefits less costs, in the sense of an economic impact analysis, or as in a benefit-cost analysis in the general theoretical sense of Drèze and Stern [1987]. Some implications for this report are that we are concerned with:

- markets that experience costs and negative benefits as well as positive benefits; and
- causal linkages, not simply with observed outcomes. An important part of this report is explicitly tracing the indirect pathways that can lead from ATP action to economic consequences.

Economic benefits are the net welfare value of "economic impacts." In other words, the long-run goal of this research project is to measure those economic impacts of DV that are relevant to an assessment of aggregate human welfare.

An economic impact is any change in the economy that is caused by a particular action or intervention. In other words, it consists of a *difference* between the world as it is, and the world as it would have been in the absence of that action. In principle, the "economic impacts" of a given action would consist in a list of all the measurable changes or differences that result from the action. In practice, we have to aggregate those measured changes into some manageable categories. This report is concerned in particular with aggregated impacts of ATP interventions on the U.S. economy.

Innovations within markets

The most important impacts of ATP stem from the R&D or technology innovations it has encouraged. We will define an innovation as a positive change in a particular technology.[3] Positive

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[3] We refer to innovations as "positive" changes, not because all innovation have positive effects on human welfare (in fact, they don't), but rather because the effects on welfare are always *potentially, weakly* positive in a rather specialized sense: given a particular metric for human welfare, no innovation leads to a *necessary* reduction in welfare. This is true simply because one option available to collective humankind is to

changes in technology are of two varieties:

- creation or introduction of new technology into a given market; or
- quality improvement in an existing technology in a given market.

Consequently, in principle there could be many innovations over time within a given technology and/or within a given market.

Then what is a technology? We define a technology as a specific means or method for serving a particular market, as (either actually or potentially) embodied in a particular product or process; or else a component or contributing feature of such a method. In principle, technologies could have component sub-technologies and sub-sub-technologies without limit. However, to keep the space of technologies tractable, we will assume that sub-technologies are not significant unless they have been given distinct names that have (or could potentially have) some notable currency in the marketplace. It follows that discrete technologies will be identified relatively naively, by observing what things have been given names in the existing market place, or in public discussion about the future market place.

Note that a given technology is not necessarily restricted to a single market. In other words, there is a many-to-many relationship between markets and technologies.

A market (as a specific disaggregation) is defined in a moderately specific manner in Burress *et al.* [1998]. Discrete markets relevant to DV have already been identified in that report, and we will assume a mapping or taxonomy of DV markets as that given there.

Quality improvements within particular DV markets are also discussed and mapped in Burress *et al.* [1998].

Modeling methods

General equilibrium modeling

This study and its series of reports attempt to embed the economic impact analysis in a computable general equilibrium (CGE) model of the US economy. However, the CGE model will actually be calculated only at a later stage of the impact analysis, for estimating what could be described as multiplier effects in all markets. This will serve the purpose of aggregating all the effects that have been measured directly or traced. In the present report, the CGE model serves mainly as an

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disregard the innovation. (This ignores the sunk costs of introducing innovations that fail in the market. Innovations are "potentially positive" from the point of view of an all-wise social planner that makes no such mistakes.) In other words, any innovation potentially increases the scope of control we collectively have over economic outcomes -- or, at worse, does not reduce our scope of control. But of course, any innovation also increases our collective power to *reduce* human welfare; so innovations are positive only to the extent that our decision-making processes are collectively rational, and in particular, lead to maximizing an accepted metric of welfare.

accounting frame that helps make clear what items are or are not different impact pathways. In particular, it defines a set of possible "contact points" that lead from ATP micro-level actions into the relatively more aggregated features of the CGE model. The CGE model is developed in Chapter 3 below.

Spillovers

"Spillovers" is a term for side effects, unintended consequences, or externalities. Jaffe [1996, 1998] described the economic impacts of ATP in terms of three classes of spillovers that flow from R&D and technology innovations (market, knowledge, and network spillovers). It is known that spillovers of R&D are of considerable importance [see e.g., Bernstein, 1989; Mansfield, 1985, as well as other sources listed the references]. To the extent possible, we will pose our empirical impact analysis in terms that are consistent with his framework. Jaffe was quite persuasive in arguing that spillovers are in a sense the "right' policy framework, so it is not a criticism to state that Jaffe used non-formal and intuitive language. However, empirical application is a different problem that requires different language. In Chapter 5 we formalize Jaffe's spillover classes. In the process, we arrive at some adjustments in the definitions of classes. In particular, we will define a number of overlapping cases; and also introduce two new classes (fiscal and material spillovers).

Pathways

In this framework, a <u>pathway</u> is a specific causal channel leading from ATP action to economic impacts. Pathways are characterized by three main features:

- the particular innovation(s) (or failed R&D attempts) that are involved
- the pattern of spillovers related to each innovation
- the contact point that the spillover makes with the CGE model.

Empirical methods

Information sources

The empirical portion of this study focuses on key DV technologies. It makes use of numerous data and information sources. To begin, we examined summaries of key DV technologies and approaches, including Poynton [1996] and Symes [1998]. We also consulted scholarly information in engineering journals, trade and popular journals, and especially electronic literature on the World Wide Web. Finally, we conducted extensive interviews with digital video experts.

Data modeling and analysis

The information gathered from the above sources was used to formulate a "technology map." The map categorizes technologies into several broad groups, and then specifies the details within the groups. In essence, the map is a comprehensive list of the technologies that are or may be used in digital video products and services.

The information, especially information from the extensive interviews, was used to inform a "map of pathways." The map of pathways lays out the potential connections between broadly- aggregated DV technology areas. The interview information was used to verify whether a potential connection did or did not occur.

Roadmap for the report

The remainder of this report is organized as follows:

- Chapter 2 gives a more detailed overview of our theoretical and empirical approaches.
- Chapter 3 describes the computable general equilibrium (CGE) model and defines the types of contact points that are possible between pathways and the CGE model.
- Chapter 4 characterizes pathways in terms of patterns of spillovers, direct effects, and contact points. It also introduces attribution models, which measure the extent to which causality can be attributed to ATP for a given spillover or direct effect.
- Chapter 5 characterizes the possible classes of spillovers.
- Chapter 6 describes an empirical map of Digital Video technologies.
- Chapter 7 gives an overview of interviews we performed with digital video experts concerning pathways of economic impact.
- Chapter 8 summarizes the individual interviews with DV experts.
- Chapter 9 lists and categorizes the significant pathways of economic impact from future digital innovations that we have been able to identify.
- Chapter 10 makes concluding remarks and suggests additional avenues for research.

Appendices to this report include additional information:

- Appendix 1 describes the Computable General Equilibrium model in formal terms.
- Appendix 2 contains some results on counting the varieties of possible spillovers with a maximum of three agents.
- Appendix 3 provides protocols used in the interviews with DV experts.
- Appendix 4 lists the DV experts who wanted to be identified by name as participating in this study, as well as the companies or institutions they were employed by.

We anticipate that this report will have a mixed audience. Chapters 3, 4, and 5 are addressed to economists and others concerned with formal justification for our approach. Chapters 6, 7, 8, and 9 address individuals with a concrete interest in digital video technology and its potential economic impacts. While some of the economic terms used in Chapters 7 and 9 are technical, we've included a non-technical glossary at the beginning of Chapter 7. Of particular interest to the non-economist will be Chapter 8, the summaries of individual interviews with DV experts.

2. METHODS

Modeling Approaches

ATP interventions can have two general kinds of direct effect on the economy: changes in technology innovations (leading to new goods and services), and changes in patterns of R&D expenditures (leading, e.g., to differences in investment and employment patterns). In addition, these *direct* effects can lead in turn to additional effects on the economy that are more *indirect* (i.e., multiplier effects). One purpose of this report is to describe or map the various *types* of potential effects of ATP, while paying considerable attention to theoretical detail and definitions of terms, and also to explain in general terms how these pathways can be measured and modeled.

By definition, any economic impact of ATP is a measured *difference* between the actual world and the counterfactual world. Therefore the measurement of an economic effect of ATP has two parts: a direct measurement in the actual world that includes ATP intervention, and a model of what the measurement would have been in a counterfactual world in which ATP did not intervene. Since we cannot directly measure what happens in the counterfactual world, every aspect of the causal links between ATP and its economic effects has to be modeled *as well as* measured.

These modeling structures are broken up into two parts:

- The indirect effects of ATP actions will be modeled using a computable general equilibrium (CGE) model of the US economy. The CGE model we will use is described in Chapter 3.
- The direct effects of ATP action are modeled by a set of "bridge models" leading from ATP intervention to the CGE model. These models are described in Chapter 4.

Bridge models

A bridge model is one that bridges the gap between ATP intervention and variables appearing in the CGE model. The most important single cause of this gap consists in differences in level of aggregation between variables measured in the "real world" (which are very disaggregated), and variables in the CGE model (which are moderately aggregated). These models also represent micro-level linkages between ATP and successful innovations, and in addition the causal linkages among various innovations (as when an innovation such as broadcast TV helps cause an innovation such a Cable TV).

Chapter 4 develops a scheme for classifying all possible patterns of linkages between ATP intervention and contact points of the CGE model. These patterns fall into two general categories, corresponding to technology innovations and R&D expenditures.

The effects of successful innovation

ATP interventions could lead eventually to commercialization of a technology innovation that otherwise would not have occurred (or, more likely, would have occurred later in time, or perhaps in a different country). The causal modeling structure we are assuming can be diagramed like this:

ATP intervention -->
    technology innovation -->
        CGE model -->
            final economic impacts

The effects of R&D and commercialization activities

ATP interventions can lead more immediately to changes in the pattern of expenditures of the economy, by (for example) diverting consumption dollars from households, first into federal taxes, and then into expenditures, in particular R&D projects that otherwise would not have occurred; or else by discouraging other R&D projects that would have occurred. This can be diagramed as:

ATP funding -->
    increased taxes, reduced services, and/or changes in investment patterns -->
        CGE model -->
            final economic impacts.

Contact points

We will refer to the point of attachment between a bridge model and the CGE model as a "contact point." A major purpose of specifying the CGE model is simply to enumerate these contact points. Every bridge model has a contact point. On the other hand, a given contact point could have more than one bridge model attached to it. An example of such a many-to-one relationship would occur if several different innovations affected by ATP intervention were aggregated together in a single sector of the CGE model.

The bridge models depend in turn on two additional modeling structures: attribution models, and spillovers. A bridge model is a chain of causation from ATP to the CGE model. Each link in the chain corresponds to an attribution model, and corresponds either to a spillover or to a direct linkage.

Attribution models

An attribution model relates an ATP intervention causally to changes in timing or location or standardization of the technology innovation that was directly funded. In other words, for each causal link relating ATP to R&D to changes in the economy, we have to evaluate the degree of responsibility that can be attributed to ATP for its occurrence. These models are considered in Chapter 4.

Causal links are of two varieties: direct links (as when R&D leads directly to commercialization of an innovation), and spillovers. In addition to spillovers that do occur and have economic impacts, it is necessary to consider spillovers that do *not* occur, but are merely anticipated. Anticipated spillovers can have important effects as barriers to R&D investment. In particular, if investors in R&D expect a major share of the benefits of innovation to spill over to bystanders, then their incentive to invest is correspondingly reduced. Thus spillovers play very two different roles:

- as transmission paths for economic impacts
- as barriers to investment

Evidently, in order to study the possible patterns of causal links and attribution models, we must also study the classes of spillovers that can occur.

Spillover classes

Jaffe [1996] gives examples belonging to three classes of spillovers, which he calls market, knowledge, and network spillovers, respectively. Jaffe does not give a formal definition of these classes. In Chapter 5 we provide formal definitions based on network diagrams of economic transactions.

Empirical implications

The modeling work contained in Chapters 3, 4, and 5 will lead to three important outputs:

- a set of modeling approaches that we plan to use in our subsequent research on the economic impacts of ATP's digital video program;
- a clear theoretical definition of the concept of an "impact pathway"; and
- guidance for the empirical work of this report, in particular for:
  - formulating the questions used in our interview protocols and interview reports; and
  - formulating the analysis used to interpret results and describe the impact pathways for digital video.

Empirical Methods

Preliminary searches

On the empirical side, we conducted an extensive search for technologies used in digital video applications. That is, we searched for the methods by which the end uses of digital video might be accomplished. We began our search for key technologies with general texts such as Poynton [1996] and Symes [1998], which clearly spell out many of the underlying approaches that make digital video work. Recent issues of trade journals including *Video Systems* and *NewMedia Magazine* acquainted us with recent developments and buzzwords. Directories of products and companies were a particularly helpful source (e.g., *Video Systems* [1998] and the list of exhibitors at COMDEX, 1998 Las Vegas). A good source of readings on market structures in video is Naom [1985]. In addition, we engaged in extensive discussions with Professor John Gauch of the University of Kansas School of Engineering concerning what technologies might support the potential *markets* for DV that we identified in our earlier report. Our preliminary investigations allowed us to define four general technology areas:

- Content Creation, Capture, and Display;
- DV Data Storage, Access, and Retrieval;
- Transmission and Management of DV Data Streams and Intellectual Property;
- End Uses of DV Data Streams.

Internet search for technologies

Within the broad framework defined above, we began to search the Internet to fill in details. What are the most prevalent approaches? What are the main issues yet to be solved? We used both top-down and bottom-up search approaches. Our top-down approach generally involved entering relevant keywords (as identified from Poynton and other sources) into a search engine, and then tracing results. Additionally, we identified websites of industry organizations and technology interest groups (such as SMPTE) and followed leads. Our bottom-up approach started with individual firms, laboratories, or researchers that we discovered during the preliminary search. We read materials on their websites, and again followed leads. When references to technologies were discovered, they were recorded and the sources were noted. Of course, not all searches yielded information about technologies, and much of the information overlapped.

Mapping of technologies

The details gained from the Internet searches were grouped by general category and sub-category to form the "technology map" presented in Chapter 6. Additional details were filled in by John Gauch at this point.

Selection of technologies for detailed interviews

Using the technology map in Chapter 6, we selected approximately 20 very specific technologies for detailed study. The initial technologies were chosen to be a fairly systematic sample among the 500+ identified DV technologies, under the following criteria:

- technologies were chosen to represent each of the four broad technology categories;
- to the extent possible, technologies were chosen to represent each of the several functional sub-categories within the technology map (such as pattern recognition or ; image capture or display;
- the selected technologies were ones that ATP might be willing to support and in which ATP had an interest..

Our intention was then to interview experts in each of the chosen areas.

Selection of telephone interviewees

We relied mainly on Internet searching to discover and locate technical experts in the selected DV technologies (we had leads on some of these people from the earlier search). These experts were selected roughly equally from the commercial sector, private research firms, and from university research laboratories. Small firms and large firms were represented about equally.

We used keywords from the technology map (Chapter 6) to begin each search. The primary search engines used were Alta Vista and Infoseek. In some instances, this method resulted in very few potential contacts. However, in most cases, many different individuals and organizations were involved in some aspect of the technology, whether in basic or applied research or in product development.

Once a list of candidates was compiled, we performed a reasonably exhaustive review of available public information on the candidates. An attempt was made to identify those who were among the foremost experts within their fields. This was accomplished by reviewing resumes and curriculum vitae, online news reports and company reviews, etc.

Individual experts who were directly involved with research were usually easy to identify and locate. This was especially true of experts from academia and research firms. However, in the commercial sector, it was sometimes necessary to contact the firm in order to locate their experts (e.g., e-mail to: info@____.com).

Once we had targeted particular experts, we invited them to participate in a telephone interview, and offered compensation consisting either in an advance copy of a report on our findings, or consulting fees. We also promised various forms of confidentiality to those who requested it:

- in some cases, particular technical approaches have been suppressed
- in some case, names and/or companies of interviewees have been suppressed.

The names of interviewees who did not request confidentiality will be included in the final version of this report. We have removed all names of interviewees from all of our individual interview reports.

Many experts and firms responded to our queries, but many others did not. Because of the iterative and eclectic nature of the search, it is not possible to calculate a response rate. Since our goal was to sample technologies, not experts, we do not believe that this problem is a serious one. However, there may well be some degree of bias with respect to the characteristics of experts recruited in this manner, and we do note the possibility that non-responding experts could have given systematically different answers to some of our questions.

Interviewees who expressed willingness to participate were then sent an e-mail form asking for additional information regarding their availability and technical expertise. Finally, a date and time were set for the interview to take place.

Interview methods

Candidate selection and interview protocols are contained in Appendix 3. Most of the interviews were tape recorded (in one case, the tape recording equipment failed). Transcripts were made of the tape recordings. Reports were then completed for each interview, based on the transcript and on additional research to check information received during the interview. These reports are summarized in Chapter 7; the complete reports constitute the substance of Chapter 8. Some of the tapes and transcripts were subsequently destroyed to protect confidentiality of some of the interviewees. Further comments on the interviews are given in the introductions to Chapters 7 and 8.

Although our interviews were intended to focus on 20 technologies, in practice the actual interviews sometimes went in unanticipated directions. Nearly every expert was knowledgeable about more than one technology, and several interviewees brought up techniques or approaches we had not previously been aware of. At the beginning of each interview, we asked the interviewee to describe several of the technologies he or she was expert on, and then focused in on one for in-depth discussion. The selection of the in-depth topic was based partly on recency of the expert's work, partly on the interviewee's stated degree of expertise, and partly on its relevance to our study. This decision was made on the fly, leading to some unplanned topics of discussion. Nevertheless, a periodic review of the completed interviews allowed us to "fill in the gaps" in technology areas that were insufficiently covered.

Summarizing Pathways

Interview questions were intended to address the relationships between the specified technologies and other technologies, and between the specified technology and consumers. Questions were to identify technical and institutional barriers to development. Although the questions themselves did not generally use the language of "spillovers" and "externalities, " these are exactly the types of issues that the interviews pursued. However, the detailed interviews cover only a very small subset of DV technologies. The connections and spillovers identified at the detailed level were numerous, and multiplied by 500 technologies would be intractable.

Instead, we use the connections found at the detailed level as e*xamples* of connections defined at a much more aggregate level: that is, we look for connections across the four broad categories of technologies. To illustrate the point, suppose that we take the category Transmission and Management of DV Data Streams. Specific technologies for multicasting educational programs (Interview 12 in Chapter 8) are included in this category. Techniques developed for multicasting may suggest new approaches for content creation (a "knowledge spillover" with this category). There will also be spillovers to "end uses of DV" as the values of services such as college courses are enhanced by multicasting techniques that make it feasible to reach a larger audience.

Summary of Methodology

We present an approach to defining, identifying, and measuring spillover effects among and between digital video technologies. On the theoretical side, our methodology first considers the effect of technological innovation on the “contact points” with a general equilibrium model of the US economy. These contact points are generally effects on end users of products and services incorporating DV technologies. The methodology then suggests using a CGE model to trace through indirect impacts. On the empirical side, we examine several very specific DV technologies, and use them to provide examples of the kinds of spillovers that are likely from DV research and development.

3. GENERAL EQUILIBRIUM CONTACT POINTS

Purpose

This as well as the next two chapters are concerned with defining the varieties of pathway that lead from ATP intervention to effects on the economy as a whole. This chapter looks at the big picture, i.e., the macro-economic aspects of those pathways. The next chapter looks at detailed micro-economic linkages to ATP without looking too closely at the idea of a spillover. The third chapter in this series provides a rigorous classification scheme for spillovers.

In particular, this chapter describes the general features of a Computable General Equilibrium (CGE) model which will be used as an analytic framework. (Formal details of the CGE model are given in Appendix 1.) This chapter also enumerates the types of entry points in the CGE model for "bridge models," which is what we call the micro-level models that lead from the initial ATP intervention into the formal CGE model. We will refer to these entry points as "contact points." An ATP intervention could affect a single type of contact point in more than way; therefore the next chapter enumerates the patterns of bridge models in more detail (and in particular, relates them to different classes of spillovers).

In general, our purposes in this report are taxonomy and enumeration rather than detailed modeling of pathways. The CGE model and the bridge models are viewed as drivers which help define the *patterns* of pathways and models that will be needed in actual measurements of technology impacts, but which do not completely specify the models in an econometric or measurement sense. Fully specifying the detailed bridge models will be part of later research in the Digital Video project.

In the context of this report, the general equilibrium framework is useful for several reasons:

- It eliminates double counting problems that arise in any partial equilibrium framework. Using partial equilibrium approaches, these problems become practically insuperable in those cases (such as the DV study) where very large numbers of markets are affected.
- Consequently, it eliminates certain redundant pathways of influence.
- It may also point to the existence of new pathways that are not entirely obvious in a partial equilibrium approach.

At a later stage in our research, the CGE framework will also provide a theory of aggregation for adding up the effects of multiple pathways of influence on the economy as a whole. Note that pathways can have negative as well as positive effects, and can interfere with each other as well as amplify each other. Embedding pathways in a model of the complete economy is the only way in which these interference effects can be sorted out systematically. Aggregation will have to be addressed when we actually measure the impacts of DV, but it is not very important for merely identifying the pathways of influence. We do not actually need to parametrize, implement, or solve the CGE model in the present report, so those tasks are reserved for later research.

Non-technically inclined readers may prefer to skip the next three sections, which give details of the model, and jump to the section below which summarizes the “Points of contact with bridge models” that are implied by our CGE model.

Some general features of any CGE model

The most fundamental property of a CGE is model is the list of the variables it contains, which are commonly categorized into four kinds. These kinds are as follows.

- “Endogenous” variables are calculated as an equilibrium solution to the behavioral rules of the model. (The behavioral rules are generally represented as a set of equations, and the equilibrium concept generally requires those equations to be satisfied simultaneously). Those equilibrium solutions are calculated conditionally on the other three kinds of variables listed below. In many dynamic or quasi-static models (including the model described here), solution equilibria are recursive, i.e., calculated separately for each time period, sequentially by time period. (In static models, there is only one time period.)
- “Predetermined” variables are calculated for a given time period based on equilibrium values of endogenous variables for previous time periods. (The predetermined variables are often defined to include initial values of the endogenous variables for “period zero,” i.e., the last period before the first period that is actually calculated within the model; but these could also be viewed as exogenous variables.)
- “Exogenous” variables are determined outside the model, but are needed inside the model. Independent measurements must be available for all of the exogenous variables. They represent influences from those parts of the world that are not being modeled. For example, if the weather were an important variable in an economic model, it would typically be treated as exogenous.
- “Parameters” are fixed constants that appear in the behavioral equations of the model. They are viewed as representing fundamental properties of the agents of the economy; an example is the average marginal propensity of households to consume (rather than save) any additional income they receive. The parameters have to be estimated separately from the CGE model, before its equilibria can be calculated. (Actually estimating those parameters depends both on having independent data sources and on making a whole series of additional modeling assumptions, which we will not address here.)

The next most fundamental property of a CGE model is its set of behavioral rules or equations and identities showing how all the variables relate to each other, together with any conditions needed to define the equilibrium concept.

A computational method or solution algorithm is a necessary addition for any CGE model. However, it is not really part of the model proper, because any CGE model has many different solution algorithms (if it can be solved at all).

For a CGE model to be of any use, its equilibrium solution or solutions must have one necessary property, as well as two additional desirable properties.

- At least one equilibrium solution must exist for the chosen set of parameters and exogenous variables. Existence can be shown either theoretically, or else empirically in the form of an actual calculated solution using a solution algorithm. Note that existence of solutions is not a trivial condition; it is entirely possible to specify a reasonable-sounding CGE model that has no solution.
- The equilibrium solution should be unique. In practice, however, sufficiently realistic dynamic models are likely to have multiple equilibria. This is problematic because we would need to know which of the multiple solutions corresponds to the "real world," a correspondence that the model itself cannot determine.
- The equilibrium solution should be stable. In other words, if endogenous variables in the economy are distorted a small distance away from equilibrium, the natural dynamics of the economy should lead towards the equilibrium and not away from it. In practice, however, it is known that dynamic CGE models that are consistent with modern economic theory are *always unstable*. (They have saddle-point instabilities.) This is problematic because a real economy could not remain at an unstable equilibrium point.

The usual manner in which CGE modelers handle unstable or multiple equilibria is to assume that some extra-model process (such as government intervention) leads the economy to select the most efficient equilibrium that is available (i.e., the equilibrium with the highest value of welfare).[4]

The CGE model described here, however, can potentially avoid both problems because it is quasi-static rather than dynamic.

Some general features of this CGE model

The model we will describe is "stripped down" to the bare fundamentals needed for the task at hand. It focuses mainly on demand functions that different sectors have for different commodities. (The commodity supply functions are then implied by the demand functions under the principle of integrability; see footnote 7.) Among all the behavioral relationships that economists have attempted to measure, we would argue that demand functions are what they have the best handle on. We would also argue that they are the most important drivers in a CGE model. Later on, we give arguments why various possible elaborations of this model are not likely to be very helpful.

As specified in Appendix 1, the model is:

- a model of the real economy, with no effort to model price levels or business cycles
- multi-sectoral (up to 500+ varieties of commodities)

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[4] Note that non-uniqueness and instability are not failings of CGE models, *per se*. Rather, they reflect innate problems within economic theory itself. Economists who believe in the natural efficiency of markets tend to distrust conventional theories that predict these instabilities. However no one has yet proposed a complete and quantitative alternative theory. Economists who believe in a need for government to correct market inefficiencies tend to believe that real-world equilibria actually are multiple and unstable.

- constant returns to scale (CRTS)
- annual and intertemporal, but quasi-static
- based on exogenous investment and technical change (i.e., technology changes are represented in bridge models, or in annual changes in parameters)
- based on competitive or average cost pricing
- able to include capacity constraints and slack capacity (for retrospective simulations).
- based on four varieties of capital: physical capital, human capital, commodity inventories, and stocks of technology knowledge
- based on representations of production and consumption purely in terms of input demands
- soluble using a known, efficient solution algorithm.

A more detailed description of this CGE model

Dynamics

The CGE model is calculated annually. The parameters of the model change each year, because of exogenous technical change; however, the model is quasi-static and time is usually not relevant.

A key issue for measuring economic impacts is whether ATP investments affect the total R&D budget or merely substitute for other R&D. We will leave that issue outside the CGE model: investment and R&D are treated as exogenous. Therefore, changes in R&D resulting from ATP activities, whether at level of micro composition or the level of macro aggregates, must be handled through external bridge models.

Nevertheless, the following intertemporal and investment-related identities are enforced endogenously:

- change in ordinary capital stock each year equals ordinary investment less capital depreciation
- change in knowledge stock each year equals new knowledge investments. (Knowledge does not depreciate, because it is defined in the model as a list of technological capabilities, rather than as a list of the current market returns to those capabilities.)

These modeling decisions are based on four considerations:

- Endogenous dynamics would lead to the problems of non-uniqueness and instability described above.
- Endogenous dynamics are not really needed to accomplish our goals of aggregation and enumeration of the contact points with ATP pathways; the only purpose would be to improve accuracy.
- In any case, we believe that extant models of savings and investment have much lower levels of accuracy and validation than models of production and consumption.

- Adding dynamics would severely limit disaggregation by commodity.[5]

(The static assumptions could be relaxed relatively easily, however. That is, most aspects of investment and savings could be endogenized in a dynamic, intertemporal CGE model.)

We will need to impose capacity constraints, at least for certain kinds of retrospective (*ex post*) simulations. (In principle, that can be handled as a part of the specification of the input demand function and factor supplies; but in practice, we believe that independent capacity constraints provide a better combination of simplicity and realism.) For forecasts (*ex ante* simulations), we may assume perfect foresight investment so that in most cases capacity is neither binding nor slack.

Kinds of goods

There are seven general kinds of flows in the CGE model. One of them consists in ordinary products:

- "commodities," i.e., ordinary goods and services. (The number of types of commodities is restricted to around 500 or less by available data; see the next section)

Six of them are related to various kinds of capital (using a very general sense of the term "capital").

- physical capital services, but excluding technology knowledge
- physical capital additions (i.e., new ordinary investment goods)
- human capital services, including labor and leisure time (treated as returns to human capital), but again excluding technology knowledge
- human capital additions (i.e., new education and work experience embodied in human beings)
- technology knowledge services
- technology knowledge additions

There are four general kinds of vectors of capital stocks in the model:

- inventories of commodities
- physical capital stocks, including land (by type and/or sector)
- human capital stocks
- technology knowledge stocks, represented as a vector of dummies for technologies available for use at time t (whether or not they are actually used). The stocks could be viewed as intellectual property rights (IPRs), although some of them may be in public domain. *A technology will be identified with a particular type of good or service available (or not available) in the economy.*

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[5] Calculating a static equilibrium with 500 commodities is within the range of computational feasibility. Adding 20 years of dynamics in a straight-forward way would potentially create up to 2x500x20 = 20,000 endogenous variables, which is not computationally feasible using presently available resources..

Numbers of goods

The major part of the data used to calibrate a multi-sectoral CGE model of the US nearly always come from the US input-output tables, which are constructed by the US Bureau of Economic Analysis. US tables are generated annually with roughly 80 commodity sectors, and at intervals of five years or longer with roughly 500 commodity sectors. However, it is possible to interpolate the 500 sector level data back to the annual periodicity. These data place an outer limit on the size of any reasonable CGE model at some 500 commodity sectors per year. (It could be more convenient in some cases to use a less disaggregated sector scheme.)

The number of commodities in the model determines, or at least places an outer bound, on the number of other types of goods and sectors. However, detailed decisions on the sector schemes are not needed for the purpose of this report.

Production

In our model, there are three kinds of output (commodities, capital investment goods, knowledge investment goods) and two kinds of production (commodities and/or investment goods, capital services).

Since we are focusing on R&D, and R&D is an investment, we will need to include separate accounts for physical capital stocks and flows, human capital sticks and flows, and knowledge capital stocks and flows in our model. Each year there is some predetermined amount of human and physical capital, inventories of commodities, and technology knowledge capital. Additions are created through production processes, and there also may be subtractions due to depreciation. (Knowledge stocks do not depreciate.) Note that R&D investments use resources in the model, but there is no necessary connection with increases in the knowledge stock; that is, the success or failure of research is exogenous to the model.

Outputs are produced with a constant returns to scale (CRTS) technology.[6] This is a significant restriction which is justified below.

Production is defined purely in terms of its (conditional or unit) input demand functions.[7] The exact

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[6] However, in the sectors that produce technology knowledge, output takes on only the discrete values 0 or 1 (meaning that know-how is either absent or present) and so the CRTS restriction has no effect on those sectors. Apart from this restriction, production of investments in physical and knowledge capital may be assumed to have the same functional forms as commodity production.

[7] The focus on demand functions is merely a way of representing the economy and is *not* a limitation on our approach. In technical terms, our approach expresses all possible direct impacts purely as changes in conditional input demand functions in each sector (including household and non-profit sectors). In a partial equilibrium setting, such an approach would be incomplete because it would omit changes in supply functions, and especially changes in productivity. (The accounting framework could be completed, for example, by

functional form is not critical because the computational algorithm treats it as a subroutine.[8]

Capital services are simply produced in proportion to existing capital stock. If there is slack demand for capital services, some of the services may be wasted; capital stocks cannot adjust in the short run.

Consumption and welfare

Households receive income from capital (including wages from human capital, profits from physical capital, and rents and royalties from knowledge capital), decides on a level of government and pay the needed taxes, and makes consumption and investment decisions. The consumption function is assumed to be in Gorman polar form, which corresponds roughly to constant returns to scale in production.[9]

Household preferences are assumed to be exogenous. The effects of technology enter the demand functions only in the sense that a given type of good is either present or absent, depending on technology and market conditions.

Analysis of welfare (i.e., the aggregate "full income" or "well-offness" of households) is not part of

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including producers surplus as well as consumers surplus in the analysis.) In a general-equilibrium setting, that is not the case. That is, under usual assumptions, the complete set of demand functions for a given actor *completely describes* the production or consumption behavior of that actor, including any changes in productivity (see e.g., Chambers [1988, p. 131]. This is sometimes referred to as "integrability," meaning that the production function and the cost function can be recovered, or "integrated," from the demand functions.) For example, any predicted increase in productivity will be expressed as a reduction in the total value of inputs demanded per unit of output. Bresnahan [1986] makes a practical application of this principle to show that the social benefits of R&D can be measured far downstream, at the level of the consumer.

We also need to make a technical comment about including third-party payments in this framework. In particular, entertainment media such as network TV commonly receive more revenue from advertisers than from the audience. We will follow the usual multi-sectoral modeling approach in which advertising or other third party services are treated as products produced jointly with the main product of the sector (i.e., entertainment). As such, their monetary values are represented by their demand functions in the normal way.

[8] It is possible that the system of equations in the model will reach extreme or unrealistic equilibrium solution points for certain demand parameters and/or functional forms; but that is a fairly generally true of general equilibrium models. Extreme solutions indicate a lack of collective realism in the set of parameters and/or functional forms, and can be handled by recalibrating or redefining the parameters. In particular, equilibria with CRTS and constant price elasticity demand functions often do converge to extreme equilibria, indicating that the price elasticities actually need to be variable and bounded. CGE models generally do need to be recalibrated so that the modeled equilibrium replicates known real-world aggregates for a target year.

[9] Gorman polar form consumption demand functions are linear-affine in income, whereas CRTS production demand functions are strictly linear in output. On the other hand, this CGE model could easily be generalized to include variable returns to scale in production that are locally approximated using linear-affine production demands. In that case, consumption and production would be almost completely parallel.

the equilibrium model itself. (This is related to the fact that utility metrics can't be directly observed.) However, once the CGE model has been solved, a conventional welfare analysis can be performed by making conventional welfare assumptions.[10]

Government

Government produces government services that are assumed to enhance welfare. Its input demands are modeled as parallel to the production input demands of firms. Its revenues come from taxes that are modeled like input demands for businesses and households.

However, ATP's fiscal flows (the taxes that pay for ATP programs, plus the expenditures made by ATP activities) will need to be singled out because they are points of contact between ATP and the wider economy.

Exports and imports

Because international spillovers of R&D are significant [Rogers,1995; Bernstein, 1995; Jaffe, Trajtenberg, and Henderson, 1993], it is important to include a trade sector. Exports are determined by exogenous demand functions which depend on prices of goods; imports are determined by endogenous demands. There is no finance sector or exchange rate. There is a vector of non-competitive import goods, and their prices are exogenous. (Consequently, we are abstracting away from most business cycle considerations.)

Prices

Most prices are assumed to be endogenous. Prices of both produced goods and capital services are competitive. (However, average cost or constant mark-up pricing are equally tractable). A subset of prices (including the price of non-competitive import goods) is taken as exogenous. In particular, the price of technology services (which corresponds to returns to intellectual property) is exogenous (and is a possible contact point for ATP influence). Prices of imported goods are exogenous. It may also be helpful to treat the wage rate or rates as the main exogenous numeraire. The real interest rate will also be exogenous.

There are no financial or monetary sectors. Inflation, unemployment, and the business cycle cannot be represented in this model.

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[10] The necessary additional assumptions are:
- we assume the money metric for utility
- we assume a particular set of reference prices for all goods that enter into utility
- we assume a particular value for the private rate of pure time preference.

Market clearing and the solution algorithm

Because of the constant returns to scale assumption, an efficient solution algorithm is available which can handle very large models. The solution computation is faster if capacity is assumed non-binding in all sectors (a pure Keynesian demand-driven world), but a solution method also exists when capacity constraints are introduced. The solution is semi-separable and recursive; in other words, the price model can be solved independently, and the quantity model can then be solved at the given prices.

How new technology goods can be added to the model

When a new commodity is introduced into the economy, it can be added into the model in two different ways: either by

- creating a whole new micro-level sector for the new commodity, or
- modifying the parameters of the pre-existing aggregate sector to which the new commodity belongs.

The first approach may be somewhat more accurate, but it is also more costly in terms of computation and modeling effort. However, this issue need not be settled until the CGE model is actually implemented.

Points of contact with bridge models

In principle, almost any parameter or exogenous variable of this CGE model could be changed as a result of ATP intervention into the US economy. Therefore a complete list of contact points consists exactly of all parameters and exogenous variables of the model. In practice, most of these possible contact points are not important, or else effects on these variables due to ATP actions would violate either the received economic theory or our basic modeling assumptions.

Points of non-contact

<u>Endogenous variables</u>

The most important variables *not* subject to direct influence by ATP are the endogenous and predetermined variables, which include:

- income, consumption demands, and welfare
- output and most output prices
- business input demands
- taxes and government demands (except ATP-related)
- depreciation of human and physical capital

Variables fixed by assumption

Other points of non-contact include:

- household demand functions. (Household preferences are fixed; technological change can cause new goods to become available, but demands for those goods are modeled as pre-existing.)
- variables predetermined in the previous year, namely stocks of capital (human, physical, and knowledge) and the corresponding production capacities

Exogenous variables judged unimportant

There are a few exogenous variables potentially influenced by ATP which we presume are not sufficiently sensitive to ATP activities to warrant being singled out as possible points of contact:

- rates of investment in human capital
- rates of inventory build-up
- rates of capital depreciation (for both human and physical capital)
- the productivity (i.e., the rate of producing capital services) received from capital stocks that exist prior to the innovation and are not replaced.

In addition, one possible point of contact is probably not of practical importance, but would have to be revisited at a later time if we add returns to scale to the model.

- market structure in a given technology sector, as reflected in the basic pricing model

In fact, the basic pricing model can easily be changed in the model (e.g., changing the degree of monopolistic competition could lead to marginal rather than average cost pricing, or to situations any where in between). However, that is not of much interest unless we also relax CRTS, because under CRTS average costs equal marginal costs.

Note that market structure outcomes depend not only on the nature of the innovation itself, but also on which firm developed the innovation, and also on other conditions that might be imposed by ATP on funded firms. The bridge model or measurement would need to take these factors into account.

Points of contact

The remaining kinds of variables can be enumerated as the major types of contact point, i.e., a list of all the important ways in which ATP is potentially able to influence the CGE model. Our interpretation is that this list characterizes all the ways in which ATP can significantly influence the macro-economy or the general level of human welfare in the US. Again, each contact point corresponds to bridge models that will need to be specified in future research (and those bridge models correspond directly to ATP's pathways of economic impact). There are two distinct varieties o f contact points:

- the direct effects of a successful innovation; and
- the direct effects of the R&D and commercialization activity itself, independently of success of the innovation.

This distinction will be important when we consider the possible patterns that can be followed by microeconomic impact pathways.

<u>The effects of successful innovation</u>

(T1) demands: the input demand functions for production or consumption.

> In other words, ATP research can lead to changes in the ways that things are produced or consumed. These change may involve the use of wholly new inputs at the level of aggregate commodities, or merely changes in the pattern of aggregate input commodities.

(T2) goods: the vector of available market goods (which affects both production input demands and household consumption demands).

> In other words, ATP research can lead to changes in what varieties of goods are available on the market.

(T3) technology rents: the prices of technology knowledge services.

> In other words, ATP research can lead to changes in monetary returns to technologies -- not only explicit royalties and licensing fees for use of intellectual property rights, but also the implicit monopoly rents which are returns to trade secrets.

(T4) terms of trade: the prices of foreign import goods.

> In other words, ATP research can lead to changes in the national location of production, causing changes in the prices we pay for imports. (Goods not imported are modeled as having infinitely high import prices.)

(T5) exports: the export demand function.

> In other words, ATP research can lead to changes in the national location of production, causing changes in what we are able to export.

<u>The effects of R&D and commercialization activities</u>

(T6) investments: the vector composition of investment decisions (including physical capital as well as R&D); and perhaps to some extent the aggregate level of saving and investment and the real interest rate as well.

> In other words, ATP research can lead directly to changes in R&D and investment decisions made by US firms that are not ATP clients. This type of contact point includes expenditures for R&D as well as subtractions from household income (or from other investment activities) that are needed to pay for the expenditures.

(T7) fiscal flows: tax cost and expenditure vector of the ATP program being evaluated (other than any R&D expenditures included under type T3).

> In other words, ATP activities necessarily entail changes in government tax and expenditure patterns, which have economic effects.

This list is the main result of this chapter that is needed in subsequent chapters of this report. (We anticipate that the entire model will be useful in subsequent research.)

Pathways that do *not* show up as contact points

It is of interest to point out certain channels of influence on the economy which are spillovers, but do *not* show up as separate points of contact for bridge models in this framework.

<u>Spillovers calculated entirely within the CGE model</u>

- There is a known externality which results from the fact that firms have a different discount rate from the social discount rate. However, this externality does *not* appear as a separate pathway or bridge model; rather, it is simply calculated implicitly by the CGE model.
- Producer's surplus is not a pathway. It is calculated implicitly inside the CGE model.
- Similarly, consumer's surplus is replaced with a direct calculation of the consumer's utility.
- Techniques: the vector of available technology knowledge services (that is, a list of all the varieties of things we know how to make at a given point in time) is not a distinct pathway. In other words, ATP research can lead to changes in what types of intellectual property rights are either held by individuals in the US or exist in the public domain. In practice, however, this channel has no separate effects on the economy as modeled; new technologies appear in the form of new goods, new technology rents, and new input demand functions.

<u>Spillovers calculated entirely within the bridge models</u>

- Failed R&D efforts provide information that can be helpful to future R&D, but this pathway does not have a direct contact point in the CGE model. Instead, it must be included within the bridge models.
- Most network spillovers occur within a single sector and are calculated as a bridge model leading into contact points of type T1. (However, see also the discussion of networks that cross sectors, in the context of returns to scale, below.)

Possible extensions of the model

This model could be extended or modified in many directions. We have declined to do so based on various considerations of simplicity, and in particular:

- Some of these extensions wouldn't essentially affect the number or general types of contact points
- Some extensions would increase the number of contact points (i.e., introduce new kinds of pathways), but the empirical usefulness of adding these new pathways seems questionable to us.

A few of the possible extensions are close calls that we may need to reconsider at a later stage of the research.

Extensions that would not change the number of contact points

The following extensions would have no appreciable effect on the number of contact points, but merely replace simple variables determined outside the model with more complicated functions determined inside the model. Approximately the same empirical work would have to done under either approach (though in different modeling forms). Because of limitations in the available modeling technology for these cases, we believe that increased endogenization would not appreciably improve the accuracy of aggregation. In most cases, there would be additional modeling problems.

- The (presently exogenous) vector of available goods could be modeled as depending on the vector of available technologies. The model of dependency would simply replace the vector of available goods as a contact point.

- The (presently exogenous) matrix of prices of technology knowledge services could be endogenized using models of price formation. The new models would replace the old exogenous prices as contact points.

- Savings could be endogenized. However, while many models of savings have been developed, it is our opinion that none of these models has much empirical validity.[11] Accordingly, endogenizing savings, while reasonably straight forward, is probably of limited empirical value (while adding very substantially to the computational cost). In any case, it merely replaces a variable with a functional relationship.

- The commodity space representation of discrete goods might be replaced with a space of characteristics of goods [Lancaster, 1971]. This is of interest because it would be consistent with the Lancastrian viewpoint used in developing our map of Digital Video technologies, as described in Chapter 6 (see also Burress *et al* [1998]). Also, it would open up additional modeling possibilities. However, existing published data sources are convenient for parametrizing a commodity representation but not a Lancastrian representation.

- In principle, R&D in the US may cause R&D in a competing country, with resulting feedbacks to the US. However, putting a game model of R&D into the CGE model would face problems of modeling and aggregation (such games occur at a level that is much more micro than even a 500 sector model can represent), as well as validation. In any case, it would merely replace contact points for import prices and export quantities with contact points consisting in new models.

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[11] For example, among the most important empirical facts about saving are

- extreme heterogeneity, even across economically similar households
- domination of aggregate private savings by the very rich
- domination of aggregate social saving by the political and ideological factors that motivate government deficits and surpluses.

None of the standard models captures any of these facts very well.

Extensions that could add additional contact points, but are empirically questionable

Some other potential extensions of the model could, in theory, improve accuracy for measuring indirect effects and aggregation results. These changes would typically also add additional types of contact points. In our view, however, the existing empirical literature needed as a basis for modeling these extensions is relatively limited, and hence any implications for accuracy are at best debatable.

- The (presently exogenous) vector of investments (i.e., additions to capital stock) could be endogenized (for example as maximizing welfare subject to the given savings, and subject to beliefs about the future). Modeling of the R&D investment decision might include technology dependencies and knowledge cascades. In addition to *accounting* for R&D dead ends and failures, it would be desirable to *endogenize* them somehow.

This extension would add additional contact points, e.g., for the effects of ATP activities on beliefs about the future returns to investments. However, it is more convenient to handle these issues inside the bridge models, rather than make them explicit in the CGE model. Again, models of investment may not be sufficiently accurate to make endogenization worthwhile.

- We could add inflation and recession effects into the CGE model.

Our model assumes that existing resources are employed so as to achieve the highest possible welfare. (If there is underemployment of some resources, that results from a temporary mismatch of capacity to demands in particular sectors, rather than from an over-all demand deficit.) In other words, we are focusing on the economic effects that ATP would have, if the economy operated efficiently in all other respects. We don't believe it would be useful to model any putative effects ATP might have in smoothing out the business cycle. Adding business cycles effects to the model would both add a great deal of complexity and at the same time make the results less easy to interpret.

- We could model extra-market effects (e.g., the effects of the economy on social pathology and environmental degradation). This could potentially add a large number of contact points, representing all of the direct effects that new technology might have on the social and biological environment.

Endogenizing these effects would be important, however, only if we reliably knew something about feedback effects from environmental conditions back to the economy. Models of this kind do exist but we think they are not yet very well-advanced. If policymakers want to know the effects of ATP on the environment, as mediated through the economy, that can be modeled most simply as a satellite model. In other words, we would first calculate the CGE equilibrium as given, and then calculate the effects of that equilibrium on the environment, ignoring any feedback from the environment to the economy.

Extensions that are close calls

We think the following omitted features are relatively important, and we might want to revisit them at a later stage of the research. (A later reconsideration is feasible in these particular cases because the needed contact points would not substantially change.)

- We could relax the CRTS assumption. This would add a new contact point for the effect of ATP on returns to scale. (However, this type of contact point is not seriously distinct from type T1 -- i.e., changes in demand functions -- and arises only because we initially assumed CRTS, which we would now relax.)

This extension is theoretically desirable because increasing returns to scale (IRTS) may explain much of the aggregate social return to new technology as well as other investments. Actually, the formal changes needed to add variable RTS to the CGE model could be rather small[12]. However, the additional data requirements for estimating the RTS parameters would be substantial, and it is not clear that we have sufficiently comprehensive and reliable information on the nature of economy-wide returns to scale to make the exercise worth-while (see e.g. Temple [1999]).

A particularly sensitive case has to with network spillovers that cross over multiple sectors of the CGE model. They can be modeled using contact points of type T1 in all of the affected sectors. However, a more natural way to model them is build the spillover in to the CGE model itself (which would introduce certain kinds of return to scale). The problem is that this cannot easily be done until a detailed analysis of each network spillover has been performed -- and that depends on work that is planned for future research.

- We could model the detailed distortions of the economy that result from taxes.

The model as specified makes conventional but simplified assumptions about tax liabilities. Taxes are known to distort economic decisions significantly.(Other causes of inefficiency in the economy, such as regulation and unnecessary limitations on the flow of information, may be equally important, but they are even harder to model than taxes.) More realistic assumptions about taxes would presumably improve the accuracy of the aggregation. However, real tax laws are extremely complicated, and modeling them always depends on making large simplifications. (In principle, we could also add new contact points for political effects of ATP funding on the marginal distortion of taxes; but implementation of that effect would be extremely sensitive to assumptions about political behavior when it comes to making small changes in tax law - and that behavior appears to be unstable.)

- We could disaggregate households by income and composition.

This addition would be worthwhile only if policy-makers are requesting specific information on the distributive effects of ATP (such as its effects, if any, on poverty). New contact points might be added for differences across households with respect to preferences for particular DV goods.

[12] because RTS can be represented (at least locally) using a linear-affine model.

Conclusion

This chapter has focused on the general types of contact or entry points into a CGE model that can result from ATP interventions in the economy. The main purposes of this chapter were:

- to make a theoretical argument that there are only a limited number specific and important types of contact points, and
- to describe and enumerate them.

Since the CGE model represents (in at least a crude way) all the things that we view as important and measurable in the economy at large, every important pathway to economic impact from ATP's digital video program can be characterized (in part) by which type of contact point it is associated with. The next two chapters show how the spillover concept can be used to further characterize these pathways, by modeling all the kinds of links that can bridge the gap between a given ATP interventions and a given type of contact point. A "pattern" -- i.e., a family of pathways-- will be identified, very roughly, as a pair consisting of a set of spillovers and/or direct channels, together with a type of contact point. An individual pathway will identified as a triple consisting of a particular initial technology, a pathway pattern, and a particular set of markets affected by the spillovers or direct channels.

4. BRIDGE MODELS, ATTRIBUTION MODELS, AND PATHWAYS

Purpose

As the reader will recall, a pathway of economic impact is identified in our framework with a small bridge model that connects the ATP intervention, occurring as it does at a very micro level, to the relatively more aggregated CGE model. This chapter characterizes the patterns of pathways or bridge models that are possible. (Actually developing the bridge models is part of the measurement problem, and as such is a task reserved for latter stages of the DV research project.)

Our approach is based partly on Jaffe's [1996] discussion of the connections between "spillovers" and ATP's interventions. The Jaffe paper has interesting and suggestive ideas about the implications of different classes of spillovers for these pathways, using a partial equilibrium framework

A "spillover" from an innovation refers to any effects or net values of the innovation that extend beyond the innovator, other than the most minimal effects of any market exchanges that result from the innovation. If a market transaction leaves both parties noticeably better off than they would be without the transaction, then they have enjoyed what is called "producers and consumers surplus," which is viewed as a "market spillover" in Jaffe's scheme. Jaffe's scheme includes two other classes of spillovers: "knowledge" spillovers, and "network" spillovers. We will expand his scheme in the subsequent chapter to include "fiscal" and "material" spillovers. The present chapter assumes only a relatively intuitive understand of these five classes.

Spillovers actually affect the pathways of economic impact in two quite independent respects:

- Once a given technology innovation comes into existence, spillovers can affect the channels through which it reaches a point of contact to the larger economy (as modeled by the CGE model). In particular, after the fact, *actual* spillovers of innovation lead to various additional benefits and costs that reach beyond the innovator. As we will see, these channels will help us directly characterize patterns of bridge models.

- Spillovers can also affect the channels through which ATP intervention helps the technology innovation come to fruition in the first place. These channels will be identified with what can be called "attribution models." For example, before the fact, *anticipated* spillovers can act as obstacles to R&D that ATP can help overcome.[13] If ATP causes an innovation by overcoming an obstacle, in a causal sense we can *attribute* the innovation to ATP. But if ATP assists an R&D

[13] The opposite effect can occur as well. That is, negative spillovers can encourage research that is not socially productive. An example is the development of a new drug that is barely superior to a pre-existing competitor. Private profits may fully reimburse private R&D costs for developing the new drug. Yet, because of negative spillovers to patents on the old drugs, the investment could be a "value sink" for society as a whole. Attribution models will need to account for negative as well as positive spillovers.

effort that actually would have succeeded even in the absence of ATP intervention, then that success can *not* be attributed to ATP. A model of this causal relationship is called an “attribution model.”

To the extent possible, this chapter will synthesize both kinds of channels with Jaffe's “spillover” framework. However Jaffe’s ideas are stated in informal fashion, and as he points out there are borderline cases that are hard to classify into particular classes. Evidently some formal theory could be helpful. In the next chapter, we will look at spillovers as abstract patterns of flow in space, which can be diagramed using particular conventions.

But first we need to sort out the ideas of attribution models and bridge models. We point out that various *degrees* of attribution of causality for an observed technology innovation might be assigned to a given ATP intervention. We also address the internal structure of bridge models. Since this structure can be quite complex, and involves the use of simpler sub-structures, we provide a method of diagraming bridge models. Note also that section 4 of Appendix 1 addresses technical problems that result from having a probability structure of attribution in connection with a CGE model.

Attribution models

ATP’s role might be described a one of overcoming the barriers to innovation that are created by spillovers. “Attribution” measures its degree of success in doing so.

In particular, spillovers may prevent an innovator from recapturing all of the social benefits of the R&D and commercialization effort [Bernstein and Nadiri,1988; Cockburn and Griliches, 1988; Goto and Kazuyuki 1989; Jaffe, 1986]; Mansfield *et al.*,1977]. Because she is aware of this in advance, her incentive is reduced. If it is reduced below a certain threshold, she may not even undertake the R&D needed for a particular innovation. This could prevent an innovation from occurring even when social benefits of the innovation outweigh the costs of R&D and commercialization. ATP intervention could help overcome this obstacle by reducing the innovator’s costs of R&D. Therefore a simplified model of attribution might be as follows.

<u>MODEL</u>
Let:

C = cost of R&D plus commercialization efforts for a successful innovation;
B = social benefits of a successful innovation;
S = value of spillovers;
B-S = incentive to innovate;
A = value to innovator of ATP intervention; and
C-A = net cost to the innovator.

Assume the R&D occurs if and only if innovator’s expected benefits exceed expected cost, i.e., if and only if B-S > C-A, and assume innovation always succeeds if R&D occurs.

If: C > B-S and C-A < B-S, then:

ATP’s causal responsibility = 100%

(because R&D and innovation did occur and would not have occurred without ATP).
Otherwise: ATP's causal responsibility = 0%
(because neither R&D nor innovation occurred, or else both would have occurred even in the absence of ATP)
(END)

More generally, it would desirable to model attribution as a continuous percentage between 0% and 100%. This percentage could be interpreted in two somewhat different ways:

- as the share of responsibility for the innovation that is due to ATP; or
- as the probability that the innovation would not have occurred in the absence of ATP.

Each bridge model needs to include one or more attribution models. For example, it is not enough to merely say that a colorimetry innovation funded by ATP in year Y led directly to sales of improved HDTV receivers with an increased value to consumers of X million dollars in year Y+1. In order to measure real economic impacts of ATP, we also need to be able to say that the innovation would not (or would) have occurred in year t in the absence of ATP intervention; or more generally, that there is a probability of P that the innovation would not have occurred in the US in year Y in the absence of ATP.

Attribution models measure the causal importance of ATP to an R&D effort or innovation. They are relatively general, in the sense that a given variety of attribution model could be used as a submodel for several different patterns of bridge model.

General patterns for bridge models (path diagrams)

By now we have introduced a number of overlapping ideas that need to be sorted out. In this section we will list the ideas, and then introduce diagrams using a symbolic notation that is helpful for categorizing the pathways.

First, pathways and bridge models refer to several kinds of objects or activities: ATP; R&D and commercialization attempts (denoted in aggregate as R&D&C); successful innovations (denoted SI); failed innovations (denoted FI); and points of contact (denoted POC).

Second, bridge models also refer to several kinds of flows or relationships: causality; degree of attribution for that causality; spillover or direct effect. We will denote all three kinds of relationships using arrows like this: -->. (Spillovers themselves are constituted from several kinds of actors and flows or relationships, and this will analyzed further in subsequent sections of this chapter.)

Furthermore, we will adopt two important conventions for interpreting these diagrams:

- the arrow sign stands for *all three kinds of things at once*. That is, it indicates that there is a potential causal connection; that the strength of the causal connection is measured using an attribution model; and that the nature of the causal connection consists either in an actual spillover, or in a direct effect.

- the degree of attribution for the pathway as a whole, equals the product of the degrees of attribution of the arrows within the pathway. That is, if ATP is 50% responsible for initiating the research, and if ATP's help is 50% responsible for the success of the innovation once initiated, and if it is 50% likely that the innovation caused an observed shift in demand, then ATP has (50%)x(50%)x(50%) = 12.5% responsibility for the observed demand shift.

Now we can diagram the two most typical kinds of bridge models using patterns like this:

(P1) ATP --> R&D&C --> SI --> POC
(P2) ATP --> R&D&C --> POC

Note that the first pattern could include a point of contact of any type from type T1 through T5, as described in the previous chapter (because those types all refer to the effects of a successful innovation). Similarly, the second pattern could include a POC of type either T6 or T7 (because those types refer to the effects of the research or commercialization activity *per se*.)

At least in principle, a bridge model with pattern P1 includes three distinct attribution models, and one with pattern P2 includes two distinct attribution models. In many cases, however, only the first one or two attribution model in the bridge model needs to be detailed - the others can be assumed to be constants (e.g., the observed R&D is assumed 100% responsible for the observed investment expenditure). But not always! For example, if two innovations occur at the same time in the same industry, and only one was backed by ATP, then we would need to sort out what share of observed changes in the industry could be attributed to the ATP-backed innovation. The key point is that every link in the causal chain needs to be examined empirically.

A very important pattern of spillover event occurs when one successful innovation induces other R&D efforts and innovations. This can be diagramed as:

(P3) ATP --> R&D&C --> SI --> R&D&C --> SI --> POC., and
(P4) ATP --> R&D&C --> SI --> R&D&C --> POC..

In these two patterns, the first three attribution models are likely to be much more important than the others. That is, it is very important to determine the ATP's degree of causality up to the second round of R&D; on the other hand, it is usually reasonable to assume that the second innovation was caused by the R&D it was preceded by.

Patterns P2, P3, and P4 actually branch off pattern P1, because they all share common paths up to the first R&D&C or SI. These dependencies will need to be taken into account in empirical applications, especially when using a probability interpretation of attribution.

Note that we could *not* have a bridge model with the pattern

ATP --> R&D&C --> FI--> POC,

for the reason that a failed innovation has no direct point of contact with the CGE model (as explained in chapter 3). On the other hand, failed innovations do sometimes have significant spillovers to other research. Hence we could have patterns such as

(P5)ATP --> R&D&C --> FI --> R&D&C --> SI --> POC., and
(P6)ATP --> R&D&C --> FI --> R&D&C --> POC..

In addition, we will also need to consider pathways of the form

(P7)ATP --> POC

which includes the direct fiscal impacts of ATP (through contact points of type T7).

In practice, patterns P5 and P6 are likely to be observed less often than P3 and P4, and those in turn less often than P1 and P2; but these more complicated patterns cannot be ignored. Patterns that are more complicated yet are clearly possible (but correspondingly more rare). In fact, the only absolute limit on the length of a chain of innovations is given by the total number of all innovations that have either occurred or failed subsequently to the first innovation in the chain. (Moreover, it would be possible to introduce a notation for joint causation, leading to whole new families of patterns with converging branches in the causal chain.) But these very complicated cases are likely to be observable in practice. Moreover, as the chains of causation get longer, more and more attribution rates are being multiplied together, so that ATP's overall degree of responsibility for the pathway will tend to fall towards zero. Therefore, in this report we will focus mainly on the patterns (P1) through (P7).

A kind of pathway or bridge model can be completely characterized by:

1. its pattern;
2. the classes of spillovers connected with each arrow in its pattern; and
3. the type of its point of contact.

The rest of this chapter analyzes the classes of spillovers and direct effects that are relevant to a particular pattern. It will prove to be helpful to separate out specific kinds of causal links within the patterns. (Also, as we shall see in the next chapter, Jaffe's spillover classes will need some clarifications and additions in order to support empirical applications.)

Spillovers analyzed by kind of elementary link

Let us define an "elementary link" as a pattern consisting of two activities connected by a single arrow -- for example, ATP --> R&D&C. Then we can say that the patterns P1 through P7 (and all other possible patterns as well) are constructed from 8 kinds of elementary causal links put together in strings, as seen below.

Different kinds of elementary links are likely to have different relationships to spillovers. In the following, we will group these kinds of links based on the nature and probable significance that spillovers are likely to have for each kind of link. However these groupings are merely rules of thumb that will need to be re-examined in empirical cases.

(a) (fiscal impacts) both connection and attribution are direct

(L1)ATP --> POC

This diagram ordinarily refers to a POC of type T7 (fiscal flows). We would assume that the ATP program is 100% responsible for its resulting fiscal impacts, in a direct manner rather than through a spillover.

(b) (initial ATP intervention) the causal connection is direct, but potential spillovers may affect the degree of attribution

(L2)ATP --> R&D&C
(L3)R&D&C --> SI.
(L4)R&D&C --> FI.

The effect of ATP on its research clients and their success is direct rather than a spillover. However, the degree of causality needs to be modeled and depends on obstacles such a potential spillovers.

(c) (induced R&D) both connection and attribution may depend on spillovers

(L5)FI --> R&D&C

The effect of a failed innovation on other R&D efforts would most likely come through a knowledge spillover (although direct market transactions are also a possibility). The degree of causal responsibility of the initial failure for the eventual success will need to be modeled.

(L6)SI --> R&D&C

The effect of a successful innovation on other R&D efforts could come through a variety of processes. The process often involve both knowledge and market processes, as well as an awareness of network spillovers. The degree of causal responsibility will need to be modeled. Here some of the processes involved:

1. development of similar and competing components (e.g., inventing around patents; a knowledge spillover)
2. development of similar but noncompeting components (in parallel markets; a knowledge spillover)

3. development of dissimilar, necessary upstream or downstream components (both a knowledge and a market spillover)
4. development of new or changed higher level network functions (a network spillover)
5. development of dissimilar and complementary components at the same level of a network (a network spillover).

(L7)R&D&C --> POC;

This linkage refers to a POC of type T7 (investments). In other words, making a particular R&D and commercialization investment (funded partly by ATP outside of usual investment channels, and partly from normal investment sources) has several effects:

1. amount and expenditure composition of this investment (a direct effect)
2. effects on all other investments, which need to be modeled.
3. a change in gross saving equal to the aggregate change in value of investment
4. a change in the rate of interest.

All these effects are market spillovers. The total change in the investment vector due to ATP includes the direct investments due to the ATP, less displaced or changed investment due to ATP, plus stimulated investment due to ATP. Simulated investment corresponds to pathway P3 leading from direct innovation to induced innovation; it is accounted for elsewhere (that is, in a different instance of this same kind of linkage) as a direct investment and thus is *not* included here.

(d) (innovation effects) both connection and attribution may depend on spillovers, and also on the type of POC.

(L8)SI-->POC.

POC = (T1) (demand functions): an innovation leads to direct changes in the way things are produced, and hence to the pattern of input demands. It may also lead to changes in aggregate production methods due to network externalities. Both changes affect the inputs that are demanded. Some of the possible channels are:

1. changes in consumption input characteristics available to households (market spillover)
2. changes in the innovating firm's own production function (not a spillover)
3. changes in other firms' production functions in the same industry (market and knowledge spillovers)
4. changes in downstream production functions (market and knowledge spillovers)
5. changes in upstream production functions (market and knowledge spillovers).

However, we are defining the concept of "direct effect of an innovation" here to exclude induced innovations (which are handled separately in pathway P5 above); the T1 contact point includes only what is inherent in the original innovation. Upstream and downstream effects will normally appear as induced innovations rather than as demand effects of the innovation, so items 4 and 5 would usually vanish in the above scheme. Also, in most cases production functions will be the same or at least very similar for all firms in the industry. Consequently, in most cases items 2 and 3 will be identical in functional form and can be aggregated.

POC = (T2) (goods): an innovation directly provides new goods in the marketplace.

POC = (T3) (technology rents): an innovation leads to changes in technology profits of two kinds:

1. direct returns to that particular kind of intellectual property.[14]
2. market spillover effects on returns to other kinds of intellectual property. (Because technology rents are exogenous to the CGE model, these spillovers would have to be modeled outside the CGE model.)

POC = (T4) (terms of trade): changing the national location of production and ownership imposes market and knowledge spillovers on import prices.

POC = (T5) (exports): changing the national location of production and ownership imposes market and knowledge spillovers on demands for US goods.

Modeling attribution

The previous structures exhaust the set of pathways, but they do not explain how to model the attribution of causality for ATP interventions. Attribution is a modeling issue that crosses all of the spillover classes. In particular, one way to model attribution is to examine the obstacles or barriers to R&D investment that were overcome by ATP intervention, and those barriers can be described in terms of some of the same spillovers that were addressed above.

In the long run, ATP probably does not "cause" any innovation per se. Rather, according to a widely accepted view of progress, important innovations are basically inevitable; if one actor does not invent them, then some other actor will invent a functionally similar innovation at a later time. Therefore attribution for an observed connection between ATP and a given technology innovation refers to changes of the following kinds:

- timing

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[14] In predictive (*ex ante*) models, we could arguably eliminate two non-spillover pathways of influence (L6)(1) and (L8)(T3)(1) (i.e., the positive and negative financial effects of the investment on the innovating firm itself) though cancellation. In particular, we might assume that expected costs equal expected benefits for the innovator. However, the needed auxiliary assumptions for such a model seem likely to be empirically false (e.g., the private discount rate does not equal the social discount rate; innovators are not risk neutral).

- sequence among innovations
- momentum (i.e., synergy and intensity of related research)
- nationality or location of intellectual property right (IPR) ownership, production, ongoing R&D
- standards and forms of implementation
- market structure

It is helpful to identify all such changes as resulting from a barrier or obstacle to innovation that is reduced by ATP intervention. (We also have to leave open the possibility that ATP will inadvertently increase barriers in certain cases, as in the case of displaced investment.) Many, or arguably all, of these barriers can be identified with spillovers.

For purposes of the present report, we do not need to actually specify the attribution models -- we are seeking only to identify pathways of economic impact, not measure them. At the same time, part of identifying the pathway consists in identifying the barriers that might be overcome with ATP's assistance. In other words, we do need to understand what potential spillovers the attribution models will depend on.

The general classes of spillovers are listed below, together with some of the corresponding barriers.

1. market spillovers:
    - failures to capture monopoly rents or other return on IP investment
    - national location of existing production and/or R&D

2. knowledge spillovers:
    - competitors in same market
    - upstream beneficiaries
    - other markets
    - national location of existing R&D

3. network spillovers:
    - creating standards
    - component networks (i.e.,
    - specialized use networks
    - quality networks
    - premature lockin (herds; information cascades; knowledge externalities)
        - changes in assessment of future choices versus changes in actual advantages due to numbers in use
    - coordination problems; picking winners
    - problems with risk-sharing
        - financial risk, research risk, commercialization risk
        - risk related to unforseen long-term consequences of major innovation
        - social versus private discount rates
        - social versus private risk aversion and skewness aversion

national location of existing production

4. fiscal spillovers:
tax burdens

5. material spillovers:
non-user or third-party benefits of innovation. (e.g., invention of a less polluting manufacturing process)

The effects of ATP on lowering these barriers have to be *modeled* as well as *measured*. For example, one way to make a measurement that aggregates the degree of attribution across all of the possible barriers is to ask members of the innovating firm a question similar to the following:

> To what extent can ATP's assistance be assigned responsibility for the success of this innovation? Please answer on a scale of 0% to 100%, where 0% indicates that your firm would certainly have succeeded even in the absence of ATP's help, and 100% indicates that your firm absolutely could not have succeeded without ATP's help.

But even if ATP's effect *on the innovating firm* has been adequately measured, we still need to model the effects of ATP's intervention on *other* firms. That is, we need to model when and where and in what form the innovation would have occurred had ATP not intervened. The modeling procedure might be:

1. identify the most important barriers that impeded other firms.
2. model the time (or space) required until those barriers could be overcome.

It will be apparent that a complete map of kinds of barriers will be necessary to this enterprise.

Furthermore, in the case of apparently *failed* ATP interventions, we will need to measure and model the effect of that failure on subsequent successful innovations by other firms.

More work is clearly needed on all of these issues. But these questions have to do with detailed measurements and models, which will be considered further in Task 3.

Summary of the "pathway" concept

A pathway is a route or channel that leads from ATP action to measurable effects on the economy as whole. To identify all of the pathways, we must:

- Identify all of the technology R&D and the intended innovations that ATP might fund directly (for an *ex ante* study), or has actually funded (for an *ex post*) study.

- For each directly funded technology innovation, identify all of the related technology innovations that might be (*ex ante*) or actually were (*ex post*) induced or assisted by the first innovation.

- For each direct or induced technology, identify the effects of an innovation on the five contact points in CGE model T1 through T5.

- For each direct or induced R&D effort, identify the effects on macroeconomic savings and investment expenditures and investment displacements and real interest rate (i.e., contact points T6 and T7 in the CGE model)

- In addition, each pathway requires attribution models for each spillover or direct effect.

A large number of very detailed pathways are included in this taxonomy. Some of the corresponding bridge models that are required may be at the forefront of existing modeling efforts, or quite possibly beyond it; but that question will be reserved for future tasks in the DV project. That is, we will probably have to follow a less (or much less) ambitious agenda than is implied by this scheme when we reach the stage of actual empirical measurements.

5. SPILLOVER TAXONOMY AND DIAGRAMS

Purpose

The preceding chapters provide a reasonably tight structure for defining pathways and bridge models in terms of patterns of spillovers and their classification, but classes of spillovers themselves have been left formally undefined.

Market and network spillovers happen as the result of market transactions, which include agents (buyers, sellers) and flows between them (dollar flows, commodity flows). In a knowledge spillover there is an additional kind of flow, namely knowledge. In an abstract sense, these elements or primitives are the components of directed networks with three kinds of flows. This suggests that it is most appropriate to define classes of spillovers in terms of particular topologies or configurations in flow networks.

Based on that intuition, the next section makes a formal analysis that provides theoretical definitions for different classes of transactions. The following sections analyze these rules to arrive at a rigorous taxonomy of spillovers. The conclusion we reach is rather inconvenient: there are an extremely large number of potential classes of spillovers. Therefore, on the empirical level, any systematic effort to test for all possible cases of spillover at any very detailed level seems likely to fail. Instead, it will be necessary to rely on some combination of aggregation and/or opportunistic or anecdotal collection methods.

Readers who want to be spared the technical details should skip to the section below on "Summary of spillover classes." Appendix 2 supplements the taxonomy of spillovers.

Proposed rules for drawing and interpreting spillover transaction diagrams

We now give a formalization of Jaffe's ideas in terms of network diagrams. As we will see, this formalization is far from being unique; however it is the simplest representation we could find that represents at least the main thrust of the distinctions Jaffe drew.

1. Network primitives:

1.1. Arrows

Three main kinds of arrows exist (spillovers).

(Interpretation: kinds of arrows = kinds of actions = kinds of spillover flows between agents)

(Interpretation: arrows point from the donor to the receiver. Hence a simple commercial exchange includes a dollar arrow from the buyer to the seller, plus a material flow arrow from the seller to the buyer.)

1.1.1. dollar flow arrows

(Interpretation: these represent either a producer or sellers surplus or a fiscal externality.)

1.1.2 material and service flow arrows

(Interpretation: these represent either a consumer surplus, an extra producer benefit, or a material external effect on third parties.)

1.1.3 knowledge flow arrows

(Interpretation: these represent either a consumer surplus, an extra producer benefit, or an externality consisting in knowledge gained by third parties.)

1.2 Nodes

Only one kind of node exists (agents).

(i.e., nodes are distinguished only by location in the diagram. Nodes may have various possible interpretations as to kind of agent, depending partly on location in the diagram.

E.g.: interpretation -- the donor of a material flow is a producer. The receiver of a material flow could be either a producer making intermediate demands, or a final consumer.)

2. Behavioral rules:

2.1 nontriviality

Any diagram has an arrow.

2.2 Agency

All arrows begin and end on nodes (representing agents).

(Interpretation: each spillover has a source and a sink.)

2.3 Interactivity

At least two nodes (agents) exist in a transaction or flow; i.e., arrows cannot begin and end on the same node.

(Interpretation: we net-out any transactions by an agent with itself.)

2.4 Causality

Any agent with an "out" arrow must have an "in" arrow.

(Interpretation: all relevant flows must be caused by an interaction. The "in" arrows are viewed as causing "out" arrows.)

(Note that agents can have "in" arrows without having "out" arrows - i.e., they can be innocent bystanders.)

2.5 Isolation

An agent with an “in” arrow need not have any “out” arrows.

(Interpretation: indirect consequences for other, pre-existing exchanges are suppressed from the diagram. More generally, all arrows in a given diagram are viewed as being tightly causally connected. That is, all are the sources and/or consequences of a single unitary process or event. In particular, we will abstract away from income and small effects on other prices and other transactions and other inputs to consumption or production for each agent, except those that are strongly caused by the initiating process or event.)

2.6 Net flow rule

Arrows of a given kind on a given pair of agents can go only 1 direction. (This rule would have to be relaxed in some empirical applications.)

(Interpretation: bidirectional flows of a given kind are assumed to net out, on the grounds that an exchange relationship is in principle possible. Netting out is assumed to be done in terms of some market or quasi-market evaluation of spillovers, so that whatever is left is a producer or consumer surplus.)

2.7. transformational invariance

Rotation of diagrams or movement of its individual agents in 2-space or 3-space does not change identity or meaning and interpretation of a diagram.

(Consequently the diagrams are “directed graphs,” and various rules of symmetry apply.)

3. Distinctions that are not *drawn*

The following distinctions are not represented in the diagrams. Obviously, adding primitives to represent these features would lead to a much more complex set of possibilities.

3.1 contractual exchange

Arrows which are part of a contractual exchange can’t necessarily be distinguished from arrows which represent pure spillovers.

(We have only three kinds of flows in our model because we are assuming that the existence of contracts and exchange agreements are not independently observable. If they were observable, then we would be able to distinguish pure spillover knowledge, pure spillover dollars, or pure spillover products, from spillover knowledge, dollars and products within a contractual relationship. In that case there would be 6 kinds of flows. Although the diagrams would obey somewhat more complex rules, vastly more distinct diagrams would be possible for any fixed number of agents. A close reading of Jaffe’s paper convinces us that the 6 kinds would be somewhat more faithful to his analysis than the three kinds we have used. However, using 6 kinds of flows would merely strengthen the conclusions that we reach below, while adding a great deal of complexity to the argument.)

3.2. Sign

Arrows are unsigned .

(In some contexts we would need to distinguish a positive arrow -- e.g., positive externality; positive payment -- from a negative arrow -- e.g., negative externality; debt owed. And simply reversing the arrow won't do, since that has a different meaning. In this paper, however, we will ignore the difference between positive and negative arrows -- i.e., we assume they lead to the same diagrams).

3.3 Kinds of agent

By rule 1.2, only one kind of agent exists.

(Rule 1.2 might be to be relaxed in some empirical applications, e.g., when we need to distinguish investment in R&D from commercial sales. But, doing so would lead to even more complex classes of possibilities.)

3.4 The initiating transaction

The transaction that initiates events (if there is one) is not explicitly designated.

(In some but not all cases we can infer an initiating event from the diagram itself. In some applications we might want to designate a particular initiating or prime exchange for all diagrams.)

4. Comments on aggregation and empirical interpretation:

In general, there could be many different ways of interpreting these diagrams onto empirical applications. First it is necessary to decide what aggregate of events constitutes and "action." For example, a "technology innovation" could be represented in various ways, such as

- as two exchange transactions (i.e., a successful innovation consisting of R&D investment -- a knowledge exchange -- followed by commercialization -- a product exchange); or
- as an isolated exchange relation (i.e., commercialization abstracted away from R&D).

Similarly, it is necessary to decide what aggregate of persons and/or firms constitute an "agent." For example, a technology owner and a manufacturer could be viewed as one agent or two; or manufacturing itself could even be subdivided by looking at subcontractors.

This interpretative freedom does not affect the theoretical argument we are making; under any fixed rules of interpretation, the issues we are addressing would still arise. This kind of interpretative indeterminacy is not a weakness of the model, because it is necessarily the case in usable economic theories. Even the most basic economic models, including the supply and demand model, have no empirical content until we make additional assumptions on aggregation and other issues.

Transactions are to be defined in least complex terms; e.g., we want strip away all unrelated exchanges that an agent participates in. Therefore we will need some interpretative rules to explain what parts of a transaction are irreducible, and what parts can be stripped away.

Some examples of simple diagrams are given in the figures. Figure 5.1 gives a legend for the three classes of spillover. The most common class of transaction would presumably consist in the simple market exchange of a product for dollars; its corresponding diagram is given in Figure 5.2.

The simplest possible diagrams

Using these rules, it is easy to show that there are exactly 6 possible diagrams with ≤ 2 agents. They are distributed as follows:

0: 0- or 1-agent diagrams (by rules 2.1 and 2.2)

3: 2-agent diagrams:

- 0: 1-arrow diagram (by rule 2.4)
- 3: 2-arrow diagrams (which can be interpreted as three kinds of pure exchange, with the kinds depending on what is being exchanged.)
- 3: 3-arrow diagrams (exchange with all three kinds of spillover present, in varying combinations of directions)
- 0: 4-arrow diagrams (by rule 2.6).

Some informative examples

The figures below contain diagrams that illustrate various interesting points. We will tell stories that provide an empirical context or situation that each diagrams could be applied to. However, one should not assume that any given diagram fits only a single possible story. On the contrary, it should be clear that the stories are non-unique concrete applications of abstract diagrams.

Figure 5.3 represents a transaction in which one manufacturer introduces a patented innovation (for example, a better picture tube) that successfully provides producers and consumers surplus. A second manufacturer then takes advantage of the knowledge that has been revealed about what works as well as what sells in the market, "invents around" the patent, and captures a portion of the exchange surplus. This diagram includes both market and knowledge spillovers. In fact, it is relatively hard to come up with stories that lead to diagrams with simple interpretations that do not contain market spillovers (but see Figure 5.8).

Figures 5.4 illustrates an upstream supplier who gains knowledge spillovers from a market transaction with a downstream manufacturer (of, for example, video equipment). The knowledge transfer is internal to the transaction, rather than external as in Figure 5.3.

Figure 5.5 shows a fiscal externality, in which a seller pays sales tax on a transaction.

Figure 5.6 could describe the effects of an automobile safety device that helped protect pedestrians (which is a possible application of DV object detection equipment). The result is a material spillover to any pedestrians who benefit from the equipment.

Figure 5.7 shows a classical network spillover in which, for example, one video-mail subscriber benefits from the decision of another individual to subscribe to video-mail as well. The entire relationship is rooted in market transactions, but the network loop is completed by a material spillover.

Figure 5.8 illustrates a network relationship involving no market transactions at all. This diagram could describe a study group or discussion circle, in which each member benefits from knowledge provided by another member, which is possible even in the absence of any direct exchange. (A digital video application of this might be a DV-mediated chat room.)

Relationships to Jaffe classes

Now we can attempt to cast light on Jaffe's spillovers scheme. Jaffe's scheme involves the three classes of spillovers "market," "knowledge," and "network." Our main problem is to provide rules that strictly place each given transaction diagram either inside or outside each given class of spillovers.

A secondary problem is whether these classes can be defined in such a way as to be disjoint -- an issue that Jaffe himself raised. Disjoint categories are highly desirable because they support crisp discussion at the theoretical level, and simple analysis at the empirical level. Overlapping categories lead to a lot of extra work.

What is the unit of analysis?

The threshold question we have to answer is: should the Jaffe classes be applied to individual arrows, or to entire diagrams? There are considerations supporting both approaches. On the one hand, it is tempting to associate the idea of a "knowledge" spillover with a "knowledge" arrow. On the other hand, the idea of "network" spillover seems to refer to something that happens at the level of an entire network diagram. "Market" spillover might be an intermediate case; it refers to an exchange relationship, which is a property that involves at least two arrows (since by assumption at least two things have to exchanged), but perhaps need not apply to all arrows in a given diagram.

However, Jaffe treated the three ideas as if they were concepts at the same level of analysis. The only way that can be done is to choose that level of analysis which is the least common denominator. For that reason, we believe the classes must refer to the diagram as whole rather than its individual arrows.

Figure 5.1

Legend:
Types of Spillovers

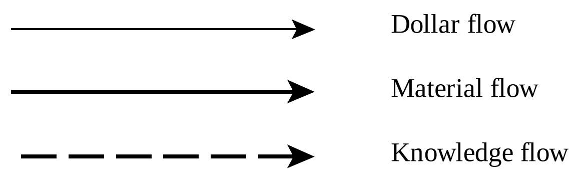


Figure 5.2

Simple exchange
(market spillovers)

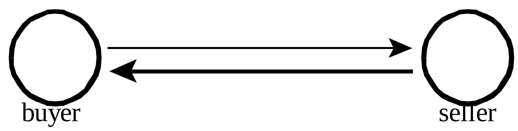


Figure 5.3

Inventing around a patent
(market and knowledge spillovers)

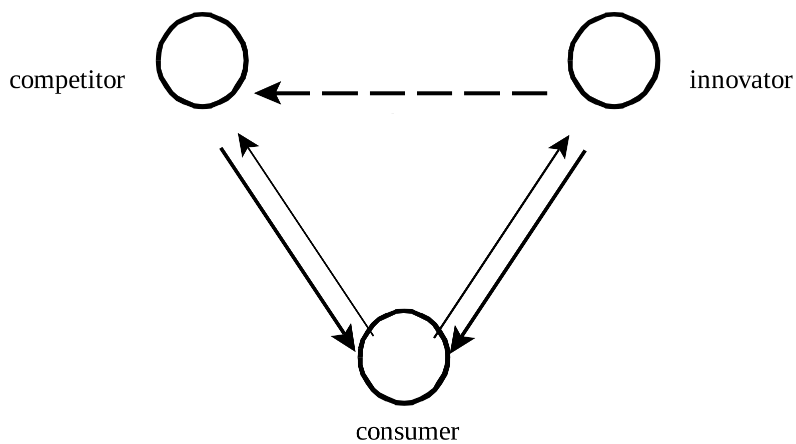


Figure 5.4

Benefits to upstream supplier
(market exchange, including knowledge)

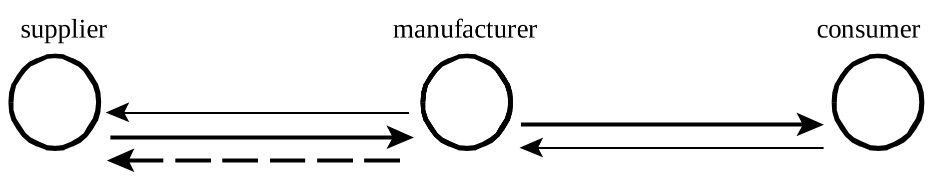


Figure 5.5

Taxation
(market and fiscal spillovers)

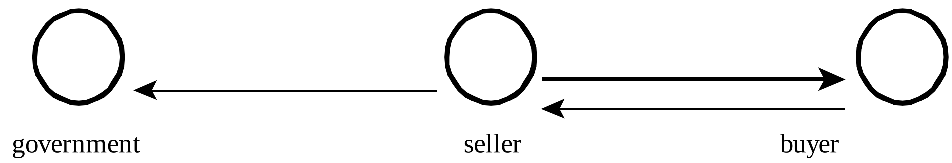


Figure 5.6

Sale of Vehicle On-board Safety Device
(market and material spillovers)

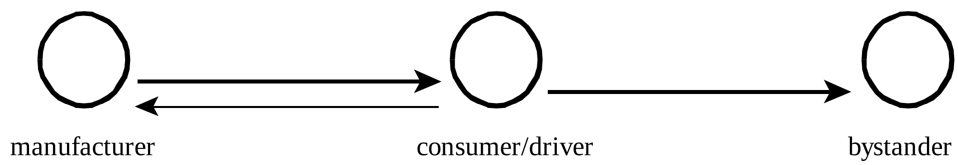


Figure 5.7

Video Mail
(market, material, and network spillovers)

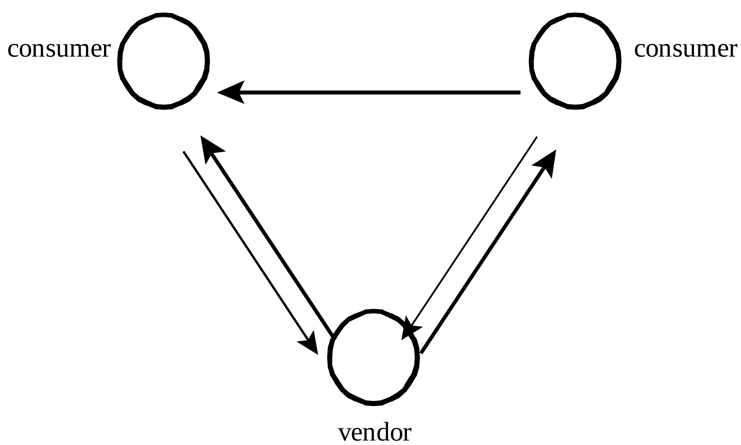
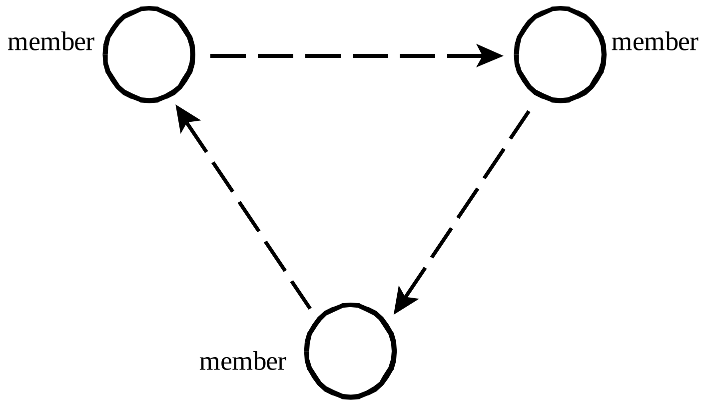


Figure 5.8

Discussion Group
(knowledge and network spillovers)



It follows immediately that Jaffe's three classes are going to have to overlap. The vast majority of cases of interest start out with an exchange relationship; such as relationship nearly always involves producers and consumers surplus, which are market spillovers. Yet many of the cases of interest also involve knowledge spillovers and/or network spillovers. It follows that knowledge and network diagrams will usually include market diagrams as well.

This conclusion is unwelcome, and suggests a need to reconsider. Is there for example some way to isolate the three classes of spillover onto the arrows that they are most intimately involved with? The answer is: even if it can be done, it won't help. The reason is that the individual arrows themselves will sometimes belong to multiple categories. In particular, we can construct network spillover diagrams in which *every link* is a market spillover. But the network spillover has to show up someplace, which would mean on an arrow that is also a market spillover.

Evidently, spillovers must refer to entire diagrams; and classes of spillovers must overlap.

Knowledge spillovers

Defining this class might seem straight-forward: it could refer to any diagram with a knowledge spillover arrow.

However, an alternative definition might be: any diagram with a knowledge arrow that is not also an exchange arrow. This definition assumes that "exchange arrow" can be adequately defined. (We will see that it can.) More importantly, it excludes knowledge spillovers within market transactions, such as figure 5.4, which Jaffe explicitly discussed as an example of a knowledge spillover. The previous, simpler definition better captures Jaffe's intent.

However, we think the second, more complex definition leads to a more understandable classification scheme. The problem is this: in our diagrams the three kinds of flow (knowledge, dollars, material products) are basically equal. Market exchanges can involve any two of them, including knowledge flows, or even all three. If we pick out knowledge flows as requiring a distinct class, then to maintain balance we also need to define spillover classes for dollar flows and for material flows (and below we will do so). Under the simpler definition, *every* market transaction would also involve at least two other classes - there would be no pure market transactions.

Therefore, we think it is more understandable to define a knowledge spillover as a knowledge flow that is not part of a market transaction; and similarly for dollar and material spillovers.

Market spillovers

The market spillover seems to refer to something of value that is transmitted through an exchange relationship. The straight-forward definition would be: market spillover refers to any diagram that contains agents that are part of either a two-way exchange, or else part of an exchange loop (such as an office gift exchange based on drawing names from a hat.)

In our formalism we do not have an explicit indicator of what is or is not an exchange; instead it must be inferred from the topology. Then how do we define an exchange, or an exchange loop?

A two-way exchange can be defined in a straight-forward fashion: it is a pair of agents connected by one or more arrows in each direction. Under our interpretative assumptions, the flows in either direction are caused by the flows in the other direction, which implies that reciprocity exists and hence it is appropriate to view this an exchange.

However, longer exchange loops present a problem (unless they consist entirely of two-way exchanges). The key question in recognizing an exchange loop is detecting the existence of an agreement between the parties rather than a mere accidental concatenation of flows. Unfortunately, there is simply no way in our formalism to tell a circular flow that is part of a network externality from one that is part of an exchange loop. Yet we want to keep the two concepts distinct.

There are apparently only two ways out of this dilemma: either provide an explicit, external marker for exchange arrows, or else restrict exchange to two way relationships. As we explained above, adding an explicit variable for exchange makes for a much more complicated formalism (without changing our qualitative conclusions).

For our purposes here we define a market spillover as any diagram which contains a two-way exchange. (But, in empirical applications if there were an external determination of which flows were, and which were not, part of bona fide contractual relationships, that information would obviously take precedence.)

Network spillovers

Here we are going to need to make some judgments.

First: multiple spillovers between the same two agents does not appear to constitute a network spillover. In principle, those spillovers would be internalized into a single exchange transaction.

Second: a linear chain of two spillovers linking 3 agents also doesn't seem much like a network externality -- because there is no feedback effect. Positive feedback seems to be inherent in the idea of (positive) network externalities; i.e., a situation such that when the size of the network increases all nodes of the network receive potentially positive benefits.

Therefore the simplest clear-cut network spillover diagram contains 3 agents and 3 spillover arrows in a circle, with all three arrows pointing the same direction around the circle. (It turns out that a total of 11 such diagrams can be distinguished, depending on the kinds and sequential order of the arrows.) A concrete example: Peter wants to call Paul, who wants to call Mary, who wants to call Peter. So other things being equal, all three are made better off when all three get a telephone. Note there is no possible 2-sided exchange that can internalize this spillover.

More generally: we define a network externality as any diagram containing a closed loop of arrows among at least three agents, such that the entire loop can be traversed by following arrows pointing in the same direction.

But there is a possible problem here. Perhaps every network spillover does involve a causal loop; but why should every causal loop imply a network spillover?

The answer is that each node in the diagram represents a behavioral relationship in which every in-arrow affects every out-arrow on that node. The diagram as a whole represents an equilibrium of these behavioral relationships. The equilibrium solution for a closed loop is very different from that for a linear chain (or open loop). For a linear chain, we simply start at the top node of the chain, solve its behavioral equations, and then solve recursively, working downward along the chain. The closed loop however leads to an irreducible set of simultaneous equations, such that every node affects every other node. This kind of simultaneity exactly captures what we mean by a network externality.

New diagram classes

As suggested above, we have identified two additional classes of transactions not discussed by Jaffe.

Fiscal spillovers

In the case of taxes and subsidies, we have a flow of dollars to or from the government that depends on the amount of the market transaction that is being taxed or subsidized. Formally, it looks the same as a knowledge spillover, except that the outward flow is in dollars rather than knowledge. (Gift relationships have similar diagrams.) This kind of situation is distinct enough to deserve a distinct name. We suggest the following definition:

A fiscal spillover is a diagram containing a dollar flow that is not part of a market exchange.

Material spillovers

Similarly, market exchanges can have material effects on non-participants. Pollution is an example of a negative material spillover.

Creating disjoint spillover diagram classes

In summary, we have identified two classes of diagrams that involve exchanges (market and network spillovers), and three classes that involve unilateral flows (knowledge, material, and fiscal spillovers).

We have also identified lots of overlapping possibilities. It is straightforward to shown that valid diagrams exist which involve many different combinations of the five identified classes.

There are, however, some kinds of overlapping classes that are not possible. This hinges mainly on the assumption that every action in the diagram is caused by some other action -- or in other words, that every node has an in-arrow (rule 2.4). It follows that somewhere in any diagram there must be a circular flow of causation (otherwise, we could trace any stream of arrows upstream until we found a node that led to nothing further upstream.) And it follows in turn that every diagram must contain either a market spillover, or a network spillover, or both.[15]

After accounting for these impossible cases, there $3x2^3-1 = 23$ disjoint classes of spillover diagrams.[16] The most irreducibly complicated class consists of diagrams that include all five classes of spillovers. (The simplest such diagram includes 4 agents and five arrows.) The potentially simplest class consists of diagrams that contain market spillovers and no other kinds (all two-agent diagrams are of this class.)

This exercise convinces us that Jaffe's three spillover classes are both irreducibly overlapping, and also incomplete. A clear taxonomy therefore will have to include many overlap classes as well as several pure classes. We might also want to add an additional class for null diagrams, representing transactions with no spillovers. Furthermore, we might do better in some cases by looking directly at the individual diagrams and viewing them as defining the primary classes of interest.

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[15] And in particular, one impossible case under these rules is the non-null diagram with no spillovers at all. A second restriction that a diagram with network spillovers but no market spillovers must have some unilateral spillovers.

[16] Three types for market, network, and combined market-network, crossed with 2^3 ways of combining the presence or absence of knowledge, fiscal, and material spillovers, less the class of network spillovers lacking either market spillovers or unilateral spillovers.

Some additional calculations: diagrams with three agents

After some involved calculations, it appears that we have (up to any calculation errors we may have made) 2463 distinct spillover diagrams with exactly 3 agents, as sketched out in Appendix 2. Of these diagrams, only 159 consist in a linear relationship with no closed loops, while 2304 of these diagrams involve a complete triangle, suggestive of network spillovers. 308 of the triangle diagrams do not involve network spillovers, however, because the directed flows fail to make a continuously circulating loop (i.e., one node has in-arrows but no out-arrows). Hence 1996 distinct diagrams include network spillovers. We also note that 2355 diagrams include exchange spillovers. 2096 diagrams include knowledge, material, and/or fiscal spillovers.[17]

Evidently, our simple rules lead to a very large number of possible transaction types.

Summary of conclusions about spillover classes

This discussion has four major implications.

First, Jaffe discussed three spillover classes: market, knowledge, and network. We believe a more balanced analytic structure results if we add two additional classes: fiscal and material.

Second, Jaffe did not give formal definitions of the classes. We have proposed formal definitions in terms of transaction flow diagrams. Those definitions can be approximately summarized in verbal terms as follows:

- A market spillover is an exchange surplus received by one party in a bilateral exchange of knowledge, dollars, and/or material goods or services.

- A knowledge, fiscal, or material spillover is surplus value of knowledge, dollars, or material goods or services received by an agent from agent when not directly engaged in a bilateral exchange.

- A network spillover is a surplus value received by an agent as part of a multilateral unidirectional closed circulation of knowledge, dollars, or material goods or services.

All classes of spillovers are understood to:

- include negative spillovers as well as positive spillovers, and
- refer to properties of a particular network of flows that are irreducibly and tightly causally linked to each other.

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[17] Because no reciprocity is involved, these three types are referred to collectively as "unilateral" spillovers in Appendix 2.

Third, it seems clear that Jaffe's three classes, and certainly our five classes, are not disjoint. In particular, nearly all possible cross-classes or overlapping categories are possible. However, there is one limit on cross classes: every spillover event must include either an bilateral exchange, or a network spillover, or both. This limit follows from the assumption that economic spillovers have to caused by an economic event.

Fourth, there is an extremely large number of detailed cases or subclasses, each represented by a distinct flow diagram. Even with only three agents and no more than three flows between any pair of agents, there are close to 3000 discrete possibilities.

Implications for DV pathways

The empirical identification of spillovers would have to start by identifying individual flows, not entire diagrams or patterns of flow. Discrete flows are much smaller in number than combinations of flows. Even so, blind or brute force tests checking for the presence or absence all possible flows in a given situation is not feasible. With 3 kinds of flows and N agents, there are 3N(N-1)/2 possible individual spillover flows for any given transaction -- a number that increases with the square of with the number of agents.

Moreover, we do not know in advance which particular outside agents might be affected by a given initiating transaction. As an example that is not at all far-fetched, suppose that an R&D investment is undertaken but fails, and suppose the knowledge of that failure become widespread. There is no straightforward way for economists to track down all of the R&D teams that took advantage of that knowledge so as to avoid R&D investments they otherwise might have undertaken.

It follows that the identification of spillovers will have to be partly anecdotal and partly based on knowing where to look. Knowing where to look means having a general knowledge of the terrain of possibilities; which is to say, the technologies that are related to each other, and the nature of those relationships. The next chapter maps in general terms the technologies that are related to digital video; the subsequent chapters examine the relationships between them.

6. A MAP OF DIGITAL VIDEO TECHNOLOGIES

Purpose and method

Our goal in this chapter is to delineate the specific technologies that underlie digital video products and markets. We began our search for such technologies by reading general texts such as Poynton [1996] and Symes [1998], which clearly spell out many of the approaches that make digital video work. In addition, we searched through recent editions of trade journals including *Video Systems* and *NewMedia Magazine* to acquaint ourselves acquainted us with recent developments. We used directories of products and companies (e.g., *Video Systems* [1998] and the list of exhibitors at COMDEX, 1998 Las Vegas) to begin an Internet search for technology details. In addition, we engaged in extensive discussions with Professor John Gauch of the University of Kansas School of Engineering concerning what technologies might support the potential *markets* for DV that we identified in our earlier report [Burress el al., 1998].

Our preliminary investigations allowed us to define four general technology areas:

- Content Creation, Capture, and Display;
- DV Data Storage, Access, and Retrieval;
- Transmission and Management of DV Data Streams and Intellectual Property;
- End Uses of DV Data Streams.

Continued Internet searching, as well as discussions with DV experts, allowed us to fill in additional detail. Within each grouping, we point out applications, methods, and standards issues. A more detailed breakout of categories is given in Appendix 5.

A fifth grouping at the end of the list contains selected features or characteristics that are not distinct technologies by themselves, but instead are quality improvements or components that could apply widely to other technologies in the list, creating distinct new sub-types. For example, a "scalable multicasting technology" would be different from a multicasting technology. The point of this last section is to show that the set of relevant technologies is much larger than any reasonably brief list can show directly, because any listed technology in the first four sections can be modified by many of the improvement types.

Once the list of technologies was developed, we submitted the list to ATP. ATP marked the technologies that they believed were outside the scope of what they have funded or might fund in the future. In the list that follows, * denotes that the technology is judged not to be of interest to ATP.

LIST OF TECHNOLOGIES

I. DV Content Creation, Capture, and Display

A1: Standard Image Capture And Display

Applications

High resolution; also superhigh definition/digital cinema:
- number of pixels
- number of frames/second
- control of distortion and artifacts
- colorimetry (and its calibration)
    - tint, intensity, brightness, contrast: color encoding
    - different color systems/improved perceptual color spaces than RGB and YIQ: YUB and XYZ
- (especially applications to digital cinema, a.k.a. superhigh definition TV)

Color patents

Screen control:
- PIP, windows

Methods and devices

* Camera lens, supports, accessories (not detailed)
* Specialized cameras/camcorders (HD, micro, surveillance)
* Studio equipment (not detailed)
* Audio transducers, equipment, and accessories (not detailed)
* Video monitor accessories (not detailed)
* Video presentation equipment (not detailed)
* Videoconferencing equipment (not detailed)
* Theater equipment (not detailed); e-cinema
* Screen types:
    - DMD (digital micromirror device)
    - LCD, CRT, projection, etc.

CCD and non-CCD cameras

Hybrid analog video

High resolution support:
- square pixels
- progressive scanning
    - progressive/interlace conversion
- human perceptual models
- color coding system
- video buffer
- compression methods

Standards and interoperability

Color encoding

Screen aspect ratios and configurations

A2. Specialized Image and Data Capture and Display
(e.g., stereo vision, user-controlled POV, smart cameras)

Applications

- Adaptive equipment for the handicapped (might also be used for equipment operation):
  - software-based visual correction
  - Tactile and aural analogs of visual fields (analog; linguistic or symbolic)
  - Visual cuing devices; virtual seeing-eye dogs (robotic vs visual analogy)
  - Eye position-based controllers
- HCI (Human-computer interface)
- Monitors/speakers, stationary
  - Wall murals/videowall/billboards/kiosks/POP (point of purchase) displays
- Video smart cards
  - (Display; camera; memory; processor; input-output)
  - (ID cards; transactions handlers; digital assistants; mailable advertising)
- Immersion improvements:
  - Stereo vision
  - 360^0 viewing
  - User-controlled POV (visual point of view) of a display
- Devices to superimpose DV information on ambient scenes (transparent images) for drivers/operators/fabricators
- Eye movement as controller input
- Wearable DV systems (micro-cameras; displays; wireless communications)
- Object and ensemble detectors
  - Object followers (2-D; 3-D) and automated camera aiming
  - Highway lane detectors
  - Vehicle and object collision detectors and predictors
- High art and museum installations
- Robot vision and control
  - Industrial, segmented by application
  - Scientific and remote exploration

Devices

- Displays:
  - 3-D glasses (active; passive -optical switching; active but transparent)
  - 3-D displays
  - head-mounted devices (HMDs) [segmented by: Games; Simulators, trainers; Factory production; machine operation; WWW and database access metaphors]
  - transparent screens
- Cameras:
  - tiny cameras/multiple locations
  - Head-mounted cameras
  - 360^0 cameras
  - stereo cameras
  - self-aiming cameras (see also object followers)

Other data input:
touch-sensitive screens
* data gloves with VR feedback (visual and tactile/force)
General/unified systems
rugged, miniature, wireless sending/receiving/memory/display/camera
wearable, hand-held, portable

Methods and features

Data capture:
Range detectors and automated camera focus
Head-position and eye position capturing and compensation
Head-position and eye position-responsive controllers and screens
psychological models for conscious eye position control and training
capturing depth information
active transmitters vs room-based sensors for wearable DV
holographic images
Data transmission and interpretation:
distributed image processing
interpolation of images
linear methods
morphing techniques
3-D modeling
coding/transmission of depth information (for 3-D)
integrate DV decoding with RISC chips for smart cards
use of compression algorithm to detect motion and estimate time to collision

Standards and interoperability

Representations for: 3-D, depth information, 360º, VR, user control data

B. Editing/presentation/authoring/production Technologies

Applications

Management and post production equipment, live and on-air suite:
TV bit-stream editing and studio networking: merging, timing, logic switching hardware/software
database and cache systems
database testing systems
synchronization of sources
latency and time offset matching, pre-roll buffers,
lip sync, hard real time insertion, frame-accurate switching
repurposing
Editing, edit suite (linear, non-linear)
frame grabber, analog capture
compositing, superimposition of images; overlays and titles; character and title generators
transitions; A/B rolls (merging two sequences); story board
trimming; removing artifacts

keyers, edit controllers
output formatting
compressed domain operations
Media conversion
telecine, film to tape
analog to digital
format conversion
Multimedia authoring, web authoring systems
Animation, special effects, and VR authoring tools
DVE (digital video effects) hardware/software, rendering
synthetic/natural hybrid coding (i.e., integrating animation with photographs)
Data visualization

Methods and devices

Editing devices and workstations
3-D editors
operations in compressed domain (fades, wipes, bugs, marquees, etc.)
editing simultaneously on compressed, analog, digital data
Virtual reality hardware/software

* Co-processor boards
* Pipe-lineable machines
* MMX
* Fast graphics

Standards and interoperability

Bitstream management standards and interoperability
VR standards and interoperability
VR modeling languages
see also: Metadata standards and interoperability

II. DV Data Storage, Access, and Retrieval

C. Storage and Retrieval

Applications

DV oriented database hardware/software; asset management systems
DV library management
video, stock footage, 3-D models, images
Automated program guides
Catalogs and directories
Web snapshots and uniform citation systems
see also: pattern recognition

Methods and devices

* Audio media and storage equipment (not detailed)
* Data systems and large databases
distributed databases

video servers
RAID (Redundant Array of Independent - or Inexpensive- Disks)
data carousels, tape library systems
* DV recorders, players, media, and small databases
tape, DVTR, DVCR
disk, DVDR, DVD, CD-ROM, DIVX
see also: Pattern recognition

Standards and interoperability

DV Hyperlink standards and interoperability
DV metalanguages, translators, and APIs (Application Programming Interfaces)
Distributed DV database standards

D. Pattern Recognition and Related Artificial Intelligence Technologies

Specific applications

Physical monitoring and control:
Object tracking
security, inventory management and automated resupply systems
Ensemble tracking
transportation management and flow control
Vehicles: highway, parking, air, tarmac, rail line, yard, harbor, pipeline
People and cargo
Human ID
personal recognition; equipment locking technology
client monitoring systems
crowd counting and modeling
Search, retrieval, and navigation aids:
image-based searching and retrieval, QBIC (query by image content)
image-based browsing and navigation
automated image indexing
automated DV synopsis
DV skimming and augmented fast forward
search results representation software
image-based web crawlers
Message and bitstream generation and control:
automated closed captioning
commercial ad detectors and trimmers
automated annotating and metadata creation
image-based message screening
Image-based site blocking
HCI (human-computer interface)
* Language understanding
Technical guides and expert system services, video-input of inventory, image-based diagnosis (repairs, service, advice; e.g., tele-mechanics; medical diagnosis; repair guides; part number

locators)
[segmented by difficulty of implementation and use:
Video hyper-manuals
True expert systems]
[segmented by expertise of user:
Consumer guides
Service rep guides
Professional user's handbook]
* Robot vision

Pattern recognition subjects

Shape-indexing and hashing
Image and sensor fusion, multi-sensor analysis
Object recognizers
Object followers
Motion analyzers
Face/iris/retina/fingerprint/voiceprint recognition
Human action analysis
Lip tracking and gesture recognition
Range measuring
Terrain describers
Scene modeling
Key frame identification
Pattern recognition languages and application generators
3-D reconstruction from 2-D DV
Automated scene separation
Training and learning;
adaption and change of target objects

Object/Pattern recognition/Computer Vision methods (see also: compression)

Active exploration vs. passive image analysis
Edge, area, shape, texture, volume detectors/describers
Image Understanding/Image Processing
feature extraction; important feature identification
feature/object segmentation
model matching
filtering/selective visualization
Image comparison/template matching
Principle component analysis
Fourier analysis etc.
eigenfaces
wavelets
multi-scale, multi-resolution
Image models of non-image data
Human perceptual models

Real-time algorithms
Distributed analysis
synchronized clocks
Classification and clustering algorithms
Neural networks, self-organizing networks

* *Pattern recognition: supporting hardware*

Very large, low latency, high bandwidth access, database systems
Very high bandwidth transmission systems
Very high throughput processors
array processors, massively parallel processors, ultrahigh cycle rates, pipelining, 3-D graphics...
High information sensors: 3-D, 360^0, multi-point, mobile, remote-controllable POV, multiple spectra (passive sound, infrared, UV, ranging radar and sonar, Doppler shift, side-looking and ground penetrating radar, chemical sensors, ...)

Standards and interoperability

Object representation language
Object description language
VR and pattern recognition algorithm representation language
Image-based navigation language

III. Transmission and Management of DV Data Streams and Intellectual Property

E. Transmission Technologies

[segmented for countries with differing TV standards and interoperability]

Applications

* Broadcasting and narrow casting systems; public and private carriers
[segmented by: infrared, radio, wired (cable and telco), satellite or DBS]
[segmented by: point of origination to program emission site, emission to receiver]
* broadband networking
* streaming (vs transfers)
compression
the DV transition: technologies needed to go from low-information broadcast to high-information broadcast (low data-->high data rate), mpeg6 - existing problems such as dropouts, premature technology lockin.
Narrow casting
access control mechanisms; conditional access technology (generalization of pay-per-view)
Loose coupling (multiple distribution networks); multiple content delivery mechanisms
* Interactive push technology/pull technology
Multichannel operation management
Multicasting
Datacasting, sales of data space

Methods and devices

Architectures: connection, connection-less, point-to-point, network, bidirectional or piggyback,

etc.
Compression:
principle components analysis
just noticeable difference
wavelets
applied models of human perception
VRML as applied to hybrid composition
see also: pattern recognition
Distributed processing:
VRML standards and interoperability
transmitting models versus data
encoding depth information
Firmware (field programmable gate arrays, FPGA); programmable logic synthesis
MPEG on DVD and direct TV
* Transmission hardware, narrow sense (send and receive predetermined signal); receiving and terminal equipment
CODECs
Transcoding equipment
Standards and interoperability
Packet transmission standards and interoperability
DV standards and interoperability:
compression standards and interoperability
metadata, essence, wrapper
see also: Metadata standards and interoperability

F. Control of Signal, Message, and Data
Pattern-recognition-related applications
Automated quality-of-web-site assessment systems
Site blocking software and censorship software; V-chips
Message screeners and scanners
Intellectual property rights enforcement (other than DV-content IPRs)
Image-based search and detection software
Image privacy enforcement systems
Cryptographic-related applications
Image privacy and security protection systems
Authentication, vouching, and watermarking (fast and secure systems)
DV camera signature and indelible date/time stamp
Other applications
Automated billing, collection, and escrow systems for video delivery systems, by type (TV stations, VOD systems, Transmission systems, Central storage service systems, DV clipping services, Royalties ...)
Use metering software, read-once technology
Copyright law enforcement software and services

QoS (Quality of Service) Control and guarantee systems
Micro-charges and billing
Video copyright protection technologies

Methods and devices

Visual encryption software (may be integrated with compression)
Automated metadata creation
Low frequency watermarking (proof against fuzzing)
Video players that detect copyrights and watermarks
Read-once vouchers

Standards and interoperability

Collective royalty collection systems (like ASCAP)
Royalty standards and interoperability
Design of legal rights to image privacy
Copyright law design
  legal rights to break up an image
Metadata standards and interoperability
Billing standards and interoperability
Bonding and certification standards and interoperability

IV. End uses of DV Data Streams

G. Communications Support and Information Support

**Transmission applications*

Loss-less compression (medicine)
Line quality guarantees; interconnection QoS
Pricing by QoS
  interruptible service systems
  "best effort" network service
QoS measurement and control:
  bandwidth: peak data rate, sustained data rate, minimum data rate
  delay: end-to-end or round-trip delay, delay variation (jitter), latency
  reliability: availability, mean time between failures, mean time to repair, errors and packet loss

Data provision applications

Video clipping services [real time; background]
Video-based information services; searchable DV database services [segmented by content: Generalized, News, Scientific, Entertainment, (See also: medical, expert systems)]
TV audience research systems

Data management applications

Answering machines
Videomail hardware/software
Database management services
Video program providers [VOD, VOND]

Methods and devices

Scalable resolution compression; incremental information
Adaptive and dynamic scaling
(Solutions to scaling-up problem)
see also: Storage and retrieval

Standards and interoperability

Conventional QoS categories, intervals, benchmarks
QoS description language
QoS auditing methods

H. Interactive Service Technologies

Applications

Bonding and certifying of Internet people and businesses
Teleconferencing; remote shared experiences
Financial transactions systems
Payment and audit services (for non-video industries)
Home and remote shopping systems
Collaboration support systems (i.e., systems to control work products as well as conferencing)
Consumer goods design, simulated display, and customization systems:
- Custom end user design
- Design for pre-marketing tests

Educational systems:
- Distance learning support services
- Programmed learning systems (e.g., the Video Linguist system)
- Conferencing systems
- Museum displays (see also: wall murals/billboards/kiosks)
- (See also: medical education; teleconferencing)

Human-computer interface (HCI) systems (see also: pattern recognition)
* Medical systems
- medical PACS - picture archiving and communications systems; esp. digital x-rays

Construction planning and project management systems:
- Architectural and engineering planning
- Project monitoring (civil and industrial engineering; buildings; landscape)
- Acoustical imaging and system installation
- Heat distribution imaging and heating/AC system installation

Human positioning and GPS systems:
- Location detection hardware/software
- Map and readout hardware/software; databases

Production process control systems [segmented by type of process]
Product testing systems
- [segmented by type of good and test]
- [segmented by type of sensing: visible, ultrahigh speed, infrared, acoustic, x-ray tomography]
- [segmented by hazardous conditions of the test]

Transportation systems:

[segmented by industry]
see also: Object tracking
Smart vehicles, vehicle guidance systems
Scheduling and reservations systems: mapping and display
Entertainment in route
Public announcement systems
Greeting card DV
Day care
Surveying
Sewers and pipelines
Real estate sales
Relays and industrial controls

Methods and devices

VR interaction of remote people
Remote screen sharing
Cooperative navigation/ dual control of screens
White board (multiple authors denoted by “chalk” color)
* Real-time audio
Large and very wide screens
Virtual merging of distributed conferees
Automated centrality of speaker
Automated “recognition” and “yielding the floor”
* Self-adaptive computer input (windows and menus)

Standards and interoperability

DV electronic data interchange

V. General Functions

This section contains some selected cross-category characteristics or components that could apply widely to other technologies listed above. For example, a “scalable multicasting technology” would be different from a multicasting technology.

Price/cost reductions

DV standards and interoperability; interoperability within functions
Interoperability across fields of endeavor (TV, computing, medicine..)
Modularity of components: e.g., screen and memory buffer, tuner, computer
Data processing efficiency (software; specialized hardware)
* Data processing power (improved hardware)
Economies of scale from increased user base
Miniaturization
Scalability
Distributed processing

Portability

Miniaturization
Wireless transmission

Standards and interoperability

- Compression
- Transmission
- Screen aspect and frame rate
- Standards and interoperability compliance testing
- System integration

User simplicity

- Interoperability
- Modularity
- Adaptive user interfaces

Upstream functions

- Compliance testing and test equipment
- Equipment developers systems
- Equipment producers systems
- Equipment suppliers systems
- Equipment operation services
- Software developers and producers
- Training and support systems

Addressing other problem areas

- Infrastructure lockout
- Legacy devices/capital inertia
- Updatability

7. SUMMARY OF INTERVIEW RESULTS

Introduction

Between August and December 1998, interviews were conducted with 21 experts involved in the development of Digital Video technologies. The purpose of the interviews was to identify the major features of particular emerging DV technologies. The focus of the interviews was on identifying the principal features of the technology or technologies with which each interviewee was expert, and determining the likely effects that these features would have upon the economic impacts of the specific technology. The focus of most questions was on specific technologies, but as we describe elsewhere, questions were designed to elicit the information necessary to determine likely market structure, and identify the pathways of economic impact for the technology in question.

Detailed reports on each of the interviews are provided in the next chapter. Here our purpose is to draw out more general patterns that emerge from aggregating the individual reports. As the detailed technology map makes clear (see Chapter 6), DV technologies are quite diverse. However, it is helpful for the purposes of interpreting the interview results to aggregate the individual technologies into a few broad categories. For the most part, the technologies examined fall fairly naturally into the four major groupings used in Chapter 6:

- DV Content Creation, Capture, and Display
- DV Data Storage, Access, and Retrieval
- Transmission and Management of DV Data Streams and Intellectual Property
- End uses of DV Data Streams

The four sections following the next section discuss technologies in each of these groupings respectively, beginning with a brief description of technological goals, and then turning to a summary of the likely pathways of economic impact. The chapter concludes with some more general observations.

The next section is a non-technical glossary, intended as an aid to readers who don't have much background in economics and do not want to wade through the earlier chapters of this report.

Glossary

A *spillover* (of a particular action by a particular agent) is a side-effect, an unintended consequence, or an externality. In the framework used here, spillovers refer quite broadly to all effects that are outside the narrow goals (that we assume are) held by the given kind of agent. For example, innovators are assumed to be motivated by the desire for profits. Hence *every* effect of a technology innovation is classified as a spillover, with the exception of any profits received by the innovator. Following Jaffe [1996], in this report we are identifying types of economic impacts with classes of spillovers.

A *knowledge spillover* is any knowledge received that is neither directly paid for nor received as part of an exchange transaction.

Fiscal spillover refers to taxes or other monetary payments that are not part of any exchange transaction.

Material spillover refers to benefits or burdens, other than knowledge or dollars, that are received outside of any exchange transaction.

Market spillover refers to producer or consumer surplus; i.e., the value received by a party in an exchange transaction, over and above the barest minimum needed to motivate the exchange.

Network spillover refers to the additional benefit or burden that happens when additional agents and/or additional objects of exchange are added to an exchange transaction. For example, each new subscriber added to a telephone company makes the telephone potentially more valuable to existing subscribers, because it adds an additional person they can call.

Market structure refers mainly to the degree of competition for buying or selling a particular kind of good. On the selling side, the extremes are perfect competition and monopoly. On the buying side, the extremes are perfect competition and monopsony.

Natural monopoly is a situation where the lowest cost of production per output unit happens when a single producer produces all of the output.

Increasing returns to scale refers to a situation where (with fixed input prices) the cost of production per unit output declines with the number of units produced. This usually leads to a natural monopoly situation.

DV Content Creation, Capture, and Display

Under this heading we include technologies related to the capture and display of DV images as well as the editing, presenting, authoring or production of DV content. Within this grouping of technologies, two narrower sub-fields can be identified. The first of these may be labeled “process” technologies because they are concerned with extending, improving, or automating traditional production tasks. The second can be labeled “product” technologies because they seek to exploit the potential of DV to create a new or qualitatively different kind of product.

Process innovations

Examples of new approaches to traditional tasks include efforts to develop non-linear editing tools (interview #5), improvements in human animation (interview #17), and the development of DV authoring tools for amateur or home users (interview #9).

By writing DV directly to a hard disk, it has become possible to randomly access video segments at separate points in time, and combine them more easily than is possible with current tape-based systems. The obstacles confronted here involve mainly a trade-off between cost and performance. Greater compression of data reduces quality but conserves on storage costs. Falling costs and increasing capacity of storage media are likely to alter this trade-off, as will increases in processing power that will make feasible more complex compression algorithms.

The problems in animation concern achieving increasingly greater realism in the replication of human images and movements. It has proved extremely difficult to create convincing animation of the human form, but the ability to do so would make it feasible to substitute animation for the use of actors in dangerous or costly settings. Limitations here involve both processing power and development of a better understanding of how human bodies or body parts appear during different kinds of activities.

Developing DV authoring tools for amateur and home use can be viewed as analogous to the transformation of typesetting that has been achieved as a result of the rapid advance of typography on home computers. By submerging the complexities of representing and manipulating DV images and providing simple and intuitive interfaces it will be increasingly possible for amateur users to produce quite good results in much the same way that they can now use word processing programs to produce quite good (though not professional quality) newsletters and other documents. Improved tools for amateurs requires both the development of better software tools and interfaces, and increased storage and processing power make it feasible to use demanding software applications and accommodate the large size of DV images.

Likely market structures

Process innovations in content creation appear relatively difficult to monopolize. Most of the fundamental insights are in the public domain, and interviewees felt that once specific solutions were found, they would suggest a wealth of alternative approaches, making it relatively easy to invent around any patents that early developers obtained. In addition, they believed that solutions were likely to be embodied in specific hardware or software systems; consequently, choices in how these systems were packaged would allow for a degree of product differentiation. At the same time, they felt that the rapid pace of technological evolution would provide an advantage to firms that were first to market and able to pursue continued development. Moreover, users will tend to develop locked-in “human capital” in the form of skills in using particular products. If the pace of fundamental technical improvement eventually slows down, then just as in the existing market for word processors, one or two market leaders could become dominant.

Market spillovers

Improved capabilities coupled with falling costs will result in gains for users of content creation and editing technologies. These must balanced against the negative effects on competing products—e.g., tape-based editing systems, human actors. As costs fall over time, the distance between the capabilities of professional systems and those aimed at the home market will be reduced, possibly squeezing out some producers of specialized content products and services.

Knowledge spill-outs and spill-ins

Video compression will be important for the foreseeable future in the area of content creation. Better compression techniques developed elsewhere will produce spill-ins, while advances in this sector will contribute spill-outs to other aspects of DV. A related, but broader issue concerns the representation of objects, people, and movements. Better understanding of how these are perceived, and can be reproduced or simulated will enhance animation, but it also has the potential to spill-over into better compression techniques, as well as the automation of image analysis, cataloging, and retrieval. Thus there may be knowledge spillovers with DV storage and access technologies.

Network spillovers

Process innovations will have network spillovers to a range of other devices that are complementary to them. These would include input devices--digital cameras (both still and motion), scanners, etc., storage media to accommodate massive amounts of DV data, processing power needed to implement the new techniques, and monitors and output devices.

Product Innovations

The transition to DV will make possible a re-envisioning of the entire nature of content. At the moment, video is viewed largely as a stream of static visual samples depicted as pixels within a rectangular image format. DV, however, encourages the creation of much richer streams of data. For example, it will be possible to transmit streams of data showing an event from various different points of view (interview #18). Viewers receiving these streams would then be able to select among a finite number of vantage points, or possibly to recombine these streams into a synthetic three dimensional representation of the event which could be viewed from any arbitrary point of view. Increased viewer interaction with video data is already being introduced via the Internet, but is constrained at the moment by bandwidth and other limitations. In addition, it will be possible to augment image streams by adding hyperlinks that could provide additional information, alternative audio tracks, advertising, or access to other streams of image data (interview #15).

Implementation of these product innovations will require process innovations to make them feasible. Efficient algorithms need to be developed for interpolating data from multiple points of view, for example, to allow reconstruction of three dimensional images and tools are needed to quickly and efficiently insert links to objects in each scene.

Likely market structures

Product innovations of the sort noted above are not likely to be protected effectively by patents. Once process innovations are developed to implement these products, there will be considerable potential for inventing around any patents. None of the interviewees believed that there was significant potential to monopolize these product markets in the near to medium term. On the other hand, as with Sony (Betamax format) and RCA (VHS format) in VCRs, having the first big success in a given format may give the first mover an opportunity to capture a substantial share of a product market.

Market spillovers

The benefits of product innovations will spillover directly to consumers who will get a more valuable product for less than they would be willing to pay for it. Suppliers of specialized kinds of content will also experience an expansion of demand for their services (e.g., sports events will become more appealing to watch).

Knowledge spill-ins and spill-outs

Advances in implementing new DV products may generate techniques relevant to computer vision or automated object recognition. Advances in these areas will also be a source of spill-ins. Improvements in compression techniques will be another source of knowledge spill-ins.

Network spillovers

Product innovations will generate new demand for hardware needed to take advantage of the capabilities being offered by expanded DV data streams. These will include better home display devices, input devices to interact with the data streams, storage media, home networking that will connect smart appliances to the lines bringing data into the house, computer chips to process data inputs, compression technologies and/or higher bandwidth transmission providers. On the production side there is likely to be increased demand for DV production tools of all sorts.

DV Storage, Access, and Retrieval

The proliferation of DV data streams will make it increasingly desirable to be able to automate the processes of filtering, sorting, cataloging, and retrieving images. Such advances will also expand the range of possible ways of interacting with and using DV data. A variety of approaches to this problem is being pursued. One approach is to compare video sequences to a known databank of sequences (interview #2). The challenge here is to be able to do this in real time, which requires use of statistical procedures to identify key components of known sequences to be compared to candidate DV sequences. Another approach (interview #13), is to develop a deeper understanding of how three dimensional objects are projected onto two dimensions from different angles and under different lighting conditions, as well as how they are perceived and recognized. This latter approach is viewed as quite difficult and unlikely to produce commercial products within the next 5-7 years, except in highly specialized settings.

Related to efforts to analyze videos is the development of a framework for linking the resulting descriptive data (metadata) to the image streams (interview #11). Metadata could be generated automatically using one of the approaches mentioned above or it might be added by the content producer at the time of production. Development of metadata frameworks requires the creation of standards of description, and cataloging of DV data and the embedding of this descriptive information as part of the data to be transmitted.

Solutions to these problems would generate products with applications across a wide variety of markets, including:

- filtering and selecting DV data for personalized viewing
- retrieving images from large image databases, video and film asset management systems
- managing video database systems, libraries
- performing industrial inspection
- creating systems for security, object tracking, etc.

Likely market structures

Basic ideas here are viewed as having a large component of common knowledge, making it easy to invent around specific patents. Markets are likely to be relatively competitive. Actual applications will tend to be quite specific (e.g., face recognition) rather than general purpose. Consequently, for some period of time there are likely to be many different and non-competing firms with related but specific expertise that may be able to move into direct competition with each other if an attractive opportunity arises.

Market spillovers

As noted, innovations in computer vision will have uses across a broad array of markets and will convey market spillovers in these settings.

Knowledge spill-ins and spill-outs

The problems here are related to real time analysis of complex data, and thus are related to artificial intelligence, statistical inference, and modeling. Consequently knowledge spillovers between these fields are likely.

Commercial applications in the foreseeable future are likely to focus on solving specific and more manageable data recognition problems. Solutions developed for one area may result in knowledge spillovers to other areas. There are also potential spillovers with compression techniques, to the extent that understanding the fundamental elements of an image, or set of motions, will yield insights about how to compress this image, and vice versa. Advances in DV animation techniques (see above) are also likely to be a source and recipient of knowledge spillovers.

Network spillovers

Advances will make DV data more valuable by allowing users to more rapidly access those images or sequences of interest to them. The effects will be to generate network spillovers for non-linear editing systems, visual databases, storage media, and the computer equipment necessary to implement data analysis in real time. Some of the varieties of networks that will evolve are:

- content networks: as a greater quantity and broader variety of DV content become available on-line, it becomes increasingly feasible to reuse existing images rather than create new ones
- equipment networks: equipment types add value to each other; for example, editing, storage, and retrieval equipment work together in broadcasting
- application networks: the same equipment may have multiple uses, as when object tracking systems handle security needs as well as inventory needs.

Transmission and Management of DV Data Streams and Intellectual Property

DV content needs to be transmitted from producers to end users, and given the interactive uses of many potential uses envisioned for DV data there needs to be provision for return communication as well. Given the diverse venues in which DV data may be employed the group of technologies aggregated under this heading is also quite varied. A related problem associated with transmission is in control of intellectual property rights. Without mechanisms to create markets in which property rights can be securely transferred from content producers to consumers, the incentives to develop DV products will necessarily be limited.

Transmission and Compression Technologies

Most applications of DV data will require relatively large bandwidths to transmit. On the one hand it is possible to expand the bandwidth available, as for example by using wave division multiplexing or other techniques to increase the density of data traveling over a single fiber optic cable (interview #1). On the other hand, it seems desirable to develop more efficient techniques of compressing data to use available bandwidth more efficiently. In the likely event that transmission capacities vary across users, and users may have access to differential processing capabilities it may be necessary to adjust transmission techniques to these differing circumstances. This creates the need for the development of protocols to manage data transmission in these circumstances to ensure the highest quality of data is conveyed in the most timely fashion, while minimizing transmission interruptions or other problems (interview # 6).

Likely market structures

In the near term, technologies are likely to be supplied in relatively competitive markets. Potential for inventing around specific implementations of particular hardware used in multiplexing is high. Network protocols by their nature are standards that must be open to everyone. In the latter case, however, there may be first mover advantages in the sense that early leaders will be able to influence standards formation in ways that enhance their own capabilities.

Another problem is that distribution systems themselves tend to be natural monopolies. For example, in wired transmission, there is no physical need for more than one wire or pipe coming into a given customer; and also no need for more than one trunk connecting adjacent customers. Also, quite apart from economies of scale in production of services, distributors have very strong incentives to merge and monopolize distribution markets - and eventually, production markets as well. In the absence of effective anti-trust action, transmission technology providers may eventually find they face a monopsonistic demand. In that case, the incentive to innovate may be substantially reduced.

Market spillovers

Expanding capacity will benefit DV content producers and consumers. Networking protocols will also have an important market among business users who need to provide distributed access to important visual databases and provide rapidly updated versions of this information for industrial maintenance, product development or other purposes.

Knowledge spill-ins and spill-outs

Increasing bandwidth will have important spillovers to and from telecommunications generally. Development of network protocols for managing transmission of data will have important spillovers with development of "aware networks," in which devices are able to communicate with each other about their current status and capacity, making possible more efficient utilization of resources attached to the network. There is also potential for spillovers between network protocols and specific transmission and compression techniques as solutions in one area may suggest approaches in the other.

Network spillovers

Increased bandwidth will benefit from, and in turn enhance the value of photonic switching devices. The need to use electronic switches is an obvious bottleneck to increasing optical fiber capacity. There are also hardware-software complementarities inherent in these technologies that will boost demand for hardware necessary to implement transmission techniques.

Intellectual Property Protection

Markets cannot work if ownership cannot be established. Establishing ownership involves embedding information about property rights in DV data in such a way that it can be easily verified, but does not impinge on image quality, and cannot be easily tampered with. The creation of digital "watermarks" that will serve this function requires algorithms for watermark production, watermark embedding, and watermark detection (interview #19).

Likely market structure

Many approaches to the problem of watermarking are possible, but there is little alternative to the adoption of some scheme. Moreover, the need for standardization may provide some basis for monopolization of provision of this service. In addition, some approaches to IP protection depend on centralized methods such as registration, which is a natural monopoly.

Market spillovers

The service will be marketed presumably to content producers, who will be the primary recipients of market spillovers.

Knowledge spill-ins and spill-outs

Watermarking is related to encryption in general, and there are likely to be knowledge spillovers in both directions. There may also be spillovers to compression technologies.

Network spillovers

Secure property rights are complementary to content creation. They may also encourage the expansion of Internet broadcasting. There is also a potential interaction with compression standards to the extent that any watermarking scheme needs to be coordinated with compression systems.

End uses of DV data streams

There are a multiplicity of potential uses for DV data streams. One important distinction is between technologies aimed primarily at households consuming prepackaged DV products generated by specialized content creators, and those intended for businesses and households that will use DV data streams to interact with one another more or less as equals (thus acting as both content producers and consumers).

Technologies for the Consumption of Prepackaged DV Content

Technologies aimed at the consumption of prepackaged DV content span a broad range of "digital appliances." In general these are emerging through the addition of some level of processing power to existing consumer electronics products or home appliances, and the possible networking of these appliances throughout the home (interviews #8 and #15). These appliances will mediate the reception of DV data streams and their display on appropriate devices. At one level such devices will be close analogs of existing home electronics devices that take advantage of the features of DV to allow users to exploit possibilities for non-linear viewing, interactive use of DV data, and the possibility of search for multimedia content at remote locations. At another level they may constitute a more far-reaching reinvention of household appliances to take advantage of potential linkages between DV images and other types of data. Such systems would interpret the different components of the DV signal and direct them to the appropriate appliances. For example, a cooking show might include recipes sent to a display device in the kitchen, and coupons sent to a home printer. The home network might also generate an automatic shopping list by comparing ingredients with inventories of goods automatically updated by a "smart" refrigerator connected to the network (interview #15).

<u>Likely market structure</u>
By analogy to existing markets for traditional household appliances, it appears likely that DV appliance markets will be competitive. The types of systems envisioned will require open standards to make possible interactivity and plug-and-play ease of use. But manufacturers will be able to distinguish and position their products through differences in features, modes of interaction, and styling.

<u>Market spillovers</u>
The principal market will be household consumers, who will receive a substantial consumers surplus. To the extent that content become more omnipresent and more usable, the total market for content may expand. In the short run there will a negative spillover to both households and content distributors in the form of forced obsolescence of existing equipment.

<u>Knowledge spill-ins and spill-outs</u>
Designing products will require learning about the characteristics of demand for different types of services and features. Knowledge generated in this way will be valuable for content creators, thus providing an important spill-out. Improvements in networking protocols, and the design of plug-and-play network protocols, are a source of spill-ins.

Network spillovers
There is a strong interaction between content creation and appliances to utilize content embodying these features. There will also be network interactions between different types of home appliances.

Technologies for Interactive Uses of DV

A variety of potential interactive uses for DV can be envisioned. These include Virtual Reality (VR) spaces for interactions with other users (interview #4), and applications of three-dimensional data representation and modeling (interview #3). Virtual reality interactions might be used for games or other recreational purposes, much as chat rooms or game sites on the Internet are already used. But they could also be used for virtual presence purposes in business for marketing, teleconferencing, collaborative work, distance learning, or the provision of medical services to remote locations. Three-dimensional modeling applications provide a means of sharing and envisioning complex data across multiple users.

Likely market structures
Potential for inventing around specific implementations is likely to be high. On the other hand, control of domains for VR interaction provides a potential for market power, as does the need for standardization around standards and protocols for effective interaction between dispersed users.

Market spillovers
There will be spillovers to households and businesses from the development of these technologies. To the extent that these technologies substitute for existing products—e.g., teleconferencing, travel, etc.—there will be negative market spillovers as well.

Knowledge spill-ins and spill-outs
There are interactions with software applications for the representation of three-dimensional information. Virtual Reality Modeling Language (VRML) may emerge as the de facto standard application, but DV product developments and modeling language developments appear to offer potential knowledge spillovers to each other. In the case of three-dimensional data representation there will also be spillovers with pattern recognition and other techniques of complex data analysis.

Network spillovers
These technologies involve substantial interaction between users. One important source of network spillovers will be from adoption decisions of other potential users. The value of the technologies will be rising as the number of users increases. The development of specialized display devices—e.g., head-mounted displays—will tend to increase the utility of these technologies, while the use of these technologies will create new demand for these specialized displays.

Spillovers to other areas

There are several classes of spillovers that we did not address above because they are both very general and, to a greater or lesser extent, relatively diffuse.

Spillovers to technology and production in general

In the discussion above we focused on network and knowledge spillovers within each of the four large categories of DV technologies. To some extent we noted the strong network interactions between the four technology areas. But this point is perhaps worth reiterating. It seems likely that advances in any of the technology groupings we have considered will have positive spillovers to the other DV technology groupings

At the same time, it should be noted that DV technologies have important linkages to other parts of the economy. DV production, distribution and consumption is highly intensive in computer processing power and data storage. As such there are likely to be strong network spillovers between improvements in the microelectronic and computer industries and the DV industry. Falling costs in these areas will make many DV technologies cheaper while increasing performance. Improved performance coupled with falling costs will make these technologies commercially feasible. At the same time, the growth of DV uses will enhance demand for microelectronic and computer devices.

Fiscal spillovers

We have not discussed the effects of technology innovation on taxation because, in general terms, taxes are a given. Nearly every company that makes profits will eventually pay corporate or personal income taxes. Nearly every employee will generate income taxes, social taxes, unemployment insurance payments, and workers compensation payments. A majority of all sales transactions will generate sales taxes. Most of the real estate and production equipment used by companies will be subject to property taxes.

Material spillovers

Nearly every form of technology innovation has material effects on bystanders in at least two ways:

- changes in the production and use of technology goods leads to changes in environmental burdens caused by waste and byproducts
- changes in the use of technology goods leads to changes in the quality of life -- such as the safety, health, and cultural milieu -- of citizens affected indirectly by those goods. Direct effects of technology usage on welfare of the user, of course, are not spillovers in this sense. However, there will be a host of indirect effects, where the use of DV by one individual has material effects on others.

Distributional effects

For nearly every class of spillover, there are negative as well as positive effects. Joseph Shumpeter famously dramatized the creative destructiveness of innovation activities in markets, meaning that every commercial success both is a cause of, and is encouraged by, other commercial and technical failures [Scherer, 1986; Caballero and Jaffe, 1993]. Even if the macroeconomic effects of a particular innovation are extremely positive, at the micro level some firms are certain to face disadvantageous economic changes.

8. REPORTS ON SELECTED DIGITAL VIDEO TECHNOLOGIES

Introduction

This chapter contains detailed reports for each of the 21 interviews we conducted with experts involved in the development of Digital Video technologies. Each interview was conducted by at least one economist and one research assistant, and typically lasted from one to one and a half hours (a few went considerably longer). The conversation was structured and guided by the interview protocol (reproduced as an Appendix to this report), but the questions asked were open ended and the interviewers exercised discretion in allowing each conversation to proceed in the most productive directions.

After completing the interview, the information gathered was written up in a standard format for subsequent analysis and reporting. The reports were reviewed and edited by all of the interviewers, supplementary information was added from outside sources, and a copy was sent to the interview subject who was asked to confirm the accuracy of the information.

As noted elsewhere, the object of the interviews was to gather detailed knowledge about specific technologies, and the features of the technologies that were likely to influence their economic impacts. Reflecting these goals, the interview reports organize the information gathered from each conversation under 6 headings:

- Technology description
- Anticipated effects in immediate markets
- Anticipated effects in related markets
- Knowledge spillovers
- Network spillovers
- Barriers to development or commercialization

The next section briefly describes the type of information reported under each of these headings.

Glossary and notes on report entries

Technology description

At the beginning of the interview each technology expert was asked to identify those technologies or products about which he or she felt most qualified to speak, and then one or more of these was selected for more detailed examination. The first section of the interview report describes the goal of the technology chosen for discussion, the techniques being pursued to achieve this goal, related technologies–both broader and narrower–and the current development status of the technology. The last item was not discussed explicitly in most of the interviews, but is based on casual empiricism. This section also contains information about selected experts and leaders involved in research in the field. To protect the confidentiality of individual respondents our informants were not listed individually as experts, unless they had been identified independently by other sources.

Anticipated effects in immediate markets

The second section of the report describes the impact that the technology is anticipated to have in the market(s) for which it is being developed. The section begins by identifying the intended market, describing possible business models for commercialization, and comparing the technology to existing substitutes. The gains to potential users from adopting the technology are described along with the current limitations of the technology and additional desirable features that will make it more attractive. The remainder of the section reports information needed to assess the likely market structure (such as competition or monopoly) under which the technology will be supplied, assessing the potential for inventing around or reverse engineering of patents or trade secrets, the likelihood of future substitute products, the ability to protect intellectual property rights, and factors affecting the national location of inventive activity and the timing of innovations.

Anticipated effects in related markets

The value of a new technology may be dependent on other related products used in combination with it. This section identifies products that are likely to be complements in the use of a particular technology, and notes any potential for bundling of products. Upstream products are those that are likely to affect production costs, and downstream products are those that are likely to use the given technology. Finally, this section notes antagonistic products, either existing or anticipated future substitutes for the technology being discussed.

Knowledge spillovers

This section assesses the potential for knowledge spill-outs in which advances in this technology area prove beneficial to researchers working on other technologies, and knowledge spill-ins in which advances in other areas are likely to provide benefits for researchers working on this technology.

Network Spillovers

One kind of network spillover occurs whenever the value of a particular product or technology is contingent on the adoption or use of other products or technologies which are not likely to be produced by the same companies (e.g., computer software and hardware). To some extent these network effects are addressed in the section on *anticipated effects in related markets*. This section describes any additional channels through which network spillovers are anticipated to occur.

Investment coordination problems will almost always be present in DV R&D (e.g., over- or under-investment under free competition or monopoly; wasteful or redundant secret research; and problems of government agencies in "picking a winner"). These generic issues are not discussed, however, unless there are technology-specific considerations.

Other areas of network spillovers discussed here include the establishment of standards, problems of coordination between hardware and software developers, the impact of existing installed base as a barrier to diffusion of new technologies, the effects of future installed base in creating "lock-in" to a particular technology, and interactions between consumers.

Economies of scale (a source of unit costs that decline with output) can be viewed a network spillover because its realization requires action by multiple agents. (For example, if individual consumers typically purchase a small share of output, then to realize any gains from large scale production, many consumers must purchase from the same producer -- a network relationship.) To the extent that R&D fixed costs are a relatively large component of many DV related technologies, it is generally anticipated that there will be economically significant increasing returns to scale (IRTS) in many of the technologies discussed here. These are not noted explicitly, unless there are technology-specific factors that require special comment.

Barriers to development or commercialization

Many of the potential barriers to development are discussed under other headings above. This section of the reports is reserved for barriers not noted in connection with other aspects of the technology. However, these barriers could also be viewed as resulting from network spillovers, in the sense that they mainly consist in failures of risk sharing in a multilateral relationship.

We have not attempted to evaluate technical engineering risk per se, so that will not be listed as a barrier, although information relevant to such considerations may be included in the section on *technology description*. If a technology gets listed in these reports at all, that implies that commercialization efforts seem to us to be at least potentially feasible within the next seven years. (In any case, ATP applicants would be expected to do a more detailed analysis of R&D risk.)

Commercialization risk is also always present; we have not listed it unless there are known problems specific to this technology and not identified elsewhere. (In any case, ATP applicants would be expected to do a more detailed analysis of commercialization risk.)

Capital availability will almost always be a potential source of market failure in R&D in general and hence DV R&D in particular (e.g., because of differences in private and social risk aversion and skewness aversion; differences in private and social discount rates; private information available to researchers but not to investors; transaction costs; asymmetric risk due to existence of bankruptcy). We have noted only special factors or particular evidence specific to this technology. (In any case, ATP applicants would be expected to do a more detailed analysis of alternate sources of capital.)

Interview 1: Wave Division Multiplexing

1. Technology description

Technology name or description: Wave division multiplexing (WDM)
Technology goal: Send more bits down the pipe for less cost
Technology technique: Superimpose signals at different wavelengths in the same optical fiber. This is in contrast with (and on top of) the existing standard technique of packet switching, which superimposes signals at the same wavelength but in different small time slots.
Current developmental status (stage, timeline, risk): WDM is already being deployed in backbones and long distance telecommunications. What needs further R&D is subsidiary technologies for protocols, etc., and for photonic switching. Both already exist in the laboratory.
Selected leaders in field (experts, firms, laboratories): CIENA, Artel, Viatel, NEC, Fugitsu
Related, broader technologies: Wired high speed transmission
Related, narrower technologies:
1. New protocols, integrated systems, management methods
2. "photonic switching," which means building routers that switch packets at various frequencies without translating back and forth with electronic signals.
3. optical multiplexers and demultiplexers
Cross-references: None identified

2. Anticipated effects in immediate markets

Intended markets:
1. common carriers of signals
2. high capacity wide area networks
Possible business models: None Identified
Existing substitutes (negatively impacted):
Single-wavelength optical transmitters and receivers
Broadband wireless transmission
Nature of gain(s) to user (as compared with existing substitutes):
Massive data transmission at greatly reduced cost
Likely limitations of technology in short-term:
High capital cost for equipment
Up to 32 channels can be multiplexed
Additional desirable features:
Tuneable lasers; lasers that operate on multiple frequencies at the same time
More channels
Photonic switching
Specialized protocols
Specialized system management software
Potential for "inventing around":
Fairly high for all components:
    hardware-multiplexers, tunable lasers,
    software-protocols, management systems
Other future substitutes: Soliton (i.e., self-sustaining pulse) transmission (which takes advantage of optical dispersion in the optical fiber).
Other factors on monopolization potential: Protocols as such cannot easily be monopolized. To the extent that they are kept proprietary, they resist universal adoption.
System management software can be monopolized because it has a fairly limited market, high R&D costs, and requires co-investment by the user in personnel skills.
The hardware components could well be sold as competitive commodities if the market gets sufficiently large.

Other factors on intellectual property protection: All hardware and software is probably protectable against direct copying by means of patents and copy-rights.
National location: US, Canada, Japan
Foreign government action: None identified
Other factors on timing of innovation: A report by Communications Industry Reports argues that photonic switching is a tougher problem than developers are admitting; many different approaches are still being tried.

3. Anticipated effects in related markets
Complementary products:
Wired networking hardware
Low dispersion and low absorption optical fibers
Potential for forced "tie-ins" of this product: None identified
Potential for forced "tie-ins" to this product: None identified
Upstream products (inputs to production of this product): (inputs to production of hardware components)
Downstream products (uses this product as input to production):
Providers of wired networking services
Antagonistic products: None identified

4. Knowledge spillovers
Potential spill-outs: Photonic switching advances would assist photonic computing
Potential spill-ins: Photonic computing advances would assist photonic switching

5. Network spillovers
Investment coordination problems: None identified
Standards problems: Protocols are standards
Hardware-software coordination: Hardware will be more useful once specialized protocols exist
Software-software coordination: None identified
Existing installed base (as a barrier): Network owners will convert slowly because of capital costs. existing single frequency techniques work fine.
Future installed base (as a source of lock-in and monopolization): The same factors will apply to the new installed base.
Other sources of premature lock-in: None identified
Economies of scale: None identified
Direct interactions between consumers (economies of consumption): None identified
Synergies with other technologies (and economies of scope): Massive increases in available bandwidth (or massive cost reductions) would have effects on all aspects of DV.
Need for development of specialized uses: Working models for applying WDM to wide area networks may take time.
Other specialized use networks using this product: None identified
Specialized use networks to which this product belongs: None identified

6. Barriers to development or commercialization
Capital availability: Capital appears to be widely available for work on all hardware aspects. Software and systems seem to be less well funded. The explanation may be that hardware has not stabilized, and potential customer base is small. (A network system need lots of photonic switches but only one management system.)
Other special barriers: None identified

Interview 2: Repetitive Message Identification

1. Technology description

Technology name or description: Repetitive message identification

Technology goal: Identify specific commercial advertising messages

Technology technique: Identify and flag a video sequence as belonging to a known databank of sequences. The main problem lies in doing this in real-time. Approaches include model-based; principal components analysis; statistical image analysis (e.g., color area distribution). It's possible to exploit pre-computed information either in the compressed image or in a digital signature. There is a trade-off surface between efficiency of algorithms, accuracy of results, number of items detected, and quantity of parallel processing needed. Particular developers in this area want their specific approaches held confidential.

Current developmental status (stage, timeline, risk): Some products are on the verge of commercialization attempts.

Selected leaders in field (experts, firms, laboratories): MIT, Xerox, SRI, Bell Labs

Related, broader technologies: Content-based DV retrieval. Subcategories include image recognition; action recognition; context analysis.

Related, narrower technologies: None identified

Cross-references: interview 13; interview 15

2. Anticipated effects in immediate markets

Intended markets:

1. Advertisers who need to monitor the actual delivery of ads
2. Viewers who want to avoid advertisements or remove them from tapes
3. Copyrighted DV content owners seeking intellectual property protection
4. Public interest organizations that want to monitor TV content over time.

Possible business models: None identified

Existing substitutes (negatively impacted):

1. Sequences can be identified from closed captioning, where it exists.
2. Sequences can be identified manually.
3. TV advertisements are counted manually.
4. Searching for copyright violations is manual and decentralized.

Nature of gain(s) to user (as compared with existing substitutes):

1. Much higher accuracy
2. Much lower price
3. Much broader coverage
4. Real-time response.

Likely limitations of technology in short-term:

1. There is a tight trade-off between size of database and speed of analysis.
2. Methods on the near-horizon will probably require exact or near-exact match of subject sequence with the databank sample.
3. Consequently, countermeasures are possible (see below). A dynamic innovation game may ensue.

Additional desirable features:

1. After watching a sequence once, viewer tells the box to block it in the future.
2. The box might determine what individual DV scenes work together as a single sequence (i.e., identify many shots in a single advertisement).
3. The device might be able to recognize variations on an original sequence (generic match).

Potential for "inventing around": Inventing around the patent is highly feasible

Other future substitutes: None identified

Other factors on monopolization potential: Difficulty of intellectual property protection for this technology reduces its monopolization potential. The demand is likely to be price-elastic (eliminating advertisements doesn't seem to be perceived as a necessity by most TV viewers), further reducing monopolization potential.

Other factors on intellectual property protection: Intellectual property protection might require combinations of trade secrets, aggressive R&D and patenting program, exploitation of first mover advantage, coalition with databank creators.
National location: US developers appear to be well ahead in this and other DV pattern recognition applications. Japan could produce some competition growing especially out of its robot vision work. France and UK are also active.
Foreign government action: None identified
Other factors on timing of innovation: None identified

3. Anticipated effects in related markets
Complementary products:
1. Databanks of commercials
2. Networking (to talk with the databanks).
3. DV recorders and editors (interfaces will be needed.)
4. Interface with set-top box (decoder) would be needed for some algorithms.
5. Competitive position of pay-TV would be enhanced.

Potential for forced "tie-ins" of this product: This product could eventually be marketed as part of an integrated package of DV searching and retrieval systems.
Potential for forced "tie-ins" to this product: None identified
Upstream products (inputs to production of this product):
1. Hardware and/or software producers (to implement the algorithm)
2. Services to capture and archive DV advertisements.

Downstream products (uses this product as input to production):
1. Advertisement placement and quantity monitoring services.
2. Intellectual property protection services for copyrighted DV content owners.

Antagonistic products:
1. Advertisers will develop techniques for introducing small random variations into each performance of a given commercial, so as to prevent avoidance by audience.
2. Advertisers will bring pressure to bear to prevent complementary goods from being deployed; e.g., interfaces to DV recorders and set-top boxes might be discouraged. Note that advertisers, TV networks, and cable distributors have substantially overlapping interests here.

4. Knowledge spillovers
Potential spill-outs:
1. Success in this field will tend to spill over into a large variety of real time DV pattern recognition problems. At the same time, most researchers believe that particular algorithms will have to be designed specifically for very narrow applications in the foreseeable future. Note that initial implementations of the present application will probably depend on exploiting an exact or near-exact match; while the majority of pattern recognition applications will require a generic match from the beginning. (Voice recognition is a successful example of this.)
2. Commercializing this application would also reveal new information about successful and failed business models for DV pattern recognition, a largely virgin territory.

Potential spill-ins:
Pattern recognition work in general.
Note that continuous voice recognition is a newly successful model.

5. Network spillovers
Investment coordination problems: None identified
Standards problems:
1. Some algorithms use coded MPEG information. Therefore changes in MPEG standards could make existing video sequence detectors obsolete.
2. Databanks and detectors will exchange condensed information, which needs to be standardized.
3. Standards are needed for signal interfaces (set-top box, recorder).

Hardware-software coordination:
1. Databanks of advertising are needed before detector systems become especially useful to consumers.
2. Detectors need to be in use before databanks become profitable.
Software-software coordination: None identified
Existing installed base (as a barrier): None identified
Future installed base (as a source of lock-in and monopolization): Databanks of advertisements in compressed form could constitute significant capital investments.
Other sources of premature lock-in:
1. MPEG standards may be developed in ignorance of needs of sequence detectors
2. Improvements in detectors could lead to changes in optimal standards for MPEG and various interfaces.
Economies of scale:
1. Databank content capture costs are independent of number of users.
2. Relative fluctuations in peak load on the databank servers falls with the size of the customer base, leading to a declining unit overhead from the peak load safety-margin.
Direct interactions between consumers (economies of consumption): None identified
Synergies with other technologies (and economies of scope): None identified
Need for development of specialized uses: None identified
Other specialized use networks using this product: None identified
Specialized use networks to which this product belongs: None identified

6. Barriers to development or commercialization
Capital availability: Not identified as an insurmountable barrier in this case. Development costs consist mainly in developing algorithms rather than hardware per se; algorithms need to be clever rather than entailing massive amounts of code, so an individual researcher with good ideas could have a large impact. Translating algorithms into hardware would require capital, as would commercialization. Active work already exists in the area.
Other special barriers: None identified

Interview 3: Applications of VRML in Enterprise Computing

1. Technology description

Technology name or description: Applications of VRML (virtual reality modeling language) in enterprise computing. That is, using real business data for business 3-D applications. The focus here is using VRML to present real data. Other potential uses of VRML are covered in reports on other interviewees.

Technology goal: Make use of 3-D for business data visualization, process visualization, and product visualization.

Technology technique: To make 3-D useful for businesses, at least four things are necessary:

1. A 3-D language. The applications under consideration use VRML.
2. Connectivity to databases so customer can use real data in 3-D applications.
3. Ability to port 3-D applications to the Web. VRML is the best mechanism presently available for doing this, just as other kinds of applications are being moved to the Web using HTML.
4. Specific tools to support data/process/product visualization.

Current developmental status (stage, timeline, risk): At commercialization stage. VRML browsers are now included as add-ins to HTML browsers, so infrastructure is widespread. VRML code is stable, whereas perhaps a year ago it was not. There are now platforms (such as those created by one interviewee's firm) to integrate enterprise data into VRML applications. The current business uses of 3-D visualization are generally high-end, such as large mining and energy companies.

Primary technical risk is that VRML may turn out NOT to be the best route to 3-D applications (as argued by some interviewees).

Existing applications development tools are primitive and limited. There are some 3-D modeling tools, but application development is still very complex.

The market is presently limited by a shortage of existing applications, and a shortage of experienced core of developers.

Selected leaders in field (experts, firms, laboratories):

Platinum Technology (http://3dbus.platinum.com)

Oracle

Related, broader technologies:

1. For data visualization: OLAP (On-line Analytical Processing)- applications that let a user slice and dice multi-dimensional data and view a particular snapshot over the Web.
2. Collaborative workplace approaches.

Related, narrower technologies:

1.VRML and similar languages.

2. Tools for constructing 3-D applications.

Cross-references: interview 4

2. Anticipated effects in immediate markets

Intended markets: Current targets are large corporations that:

a) have applications that are inherently spatial, and for whom it is critical to actually see three dimensions. Examples are mining and energy companies.

b) are working with highly complex multi-variable information using continuous variables that depend on time. Examples are financial firms.

Eventual targets would include all firms producing complex, customized, or variable physical products, or with complex production or service processes.

Possible Business Models:

1. Conventional sales of software for 3-D visualization tools. Code could be propriety, or profits could come from sales of manuals, support, consulting, technical updates.
2. Sales of data visualization services and consulting

Existing substitutes (potentially negatively impacted):

Analysis using static and 2-D representations of 3-D data.

Non-visual statistical techniques.

Less collaborative ways of using data.

Nature of gain(s) to user (as compared with existing substitutes): Allows user to incorporate real data into 3-D moving image. 3-D imaging may make complex data easier to understand. Can simulate process flows with a time element.
Likely limitations of technology in short-term: Primitive nature of visualization tools
Additional desirable features: Applications could be static 3-D, 4-D in the sense of 3-D changing across time (true 3-D videos), or pseudo- 4-D, with time serving as a proxy for some continuous control variable. Ability to make use of real-time data.
Developers' tools are needed, and further down the road, even simpler tools to let more "ordinary people" use 3-D data are needed. These tools don't really exist yet.
Potential for "inventing around":
1. Could use another approach rather than VRML.
2. There is high potential to replicate functionality of a given visualization tool using alternative code. The basic concepts are well known and probably not patentable per se.
Other future substitutes: Advanced but non-visual methods of data exploration and analysis; e.g., non-visual neural nets.
Other factors on monopolization potential: None identified
Other factors on intellectual property protection: Developers of business applications of 3-D have in general favored an open approach to the underlying 3-D code. Intellectual property protection then depends on know-how and "staying ahead."
National location: On the supply side, U.S. is dominant. Japan (Sony) and Germany also have developers. Interestingly, there has been more interest from customers in Europe and Australia that from U.S.
Foreign government action: None identified
Other factors on timing of innovation: In order for businesses uses to become more widespread, a core of developers will be needed.

3. Anticipated effects in related markets
Complementary products: Applications that can benefit from 3-D visualization.
Software tools for developing applications (in addition to data visualization tools)
Potential for forced "tie-ins" of this product: Tie-ins with web browsers and databases
Potential for forced "tie-ins" to this product: None identified
Upstream products (inputs to production of this product): Lots of processor power. Fast graphics acceleration chips. 3-D headsets and other viewing mechanisms (currently such viewing mechanisms exist only at the very high end –nothing at the consumer level).
Downstream products (uses this product as input to production): Developing virtual collaborative work environments (Sony). Educational applications.
Nearly any production process could potential use this technology for process control.
Antagonistic products: (possibly) 3-D approaches based on something other than VRML.

4. Knowledge spillovers
Potential spill-outs: According to one interviewee, "a lot of problems that we are trying to solve for purely data visualization applications also apply to multi-use applications and collaborative applications. Examples are how to communicate data between computers, and how to bring people together electronically in real time."
Potential spill-ins: Continued advancement in 3-D languages. Also, 3-D is hardware intensive and uses specialized hardware, so hardware improvements will allow expanded capabilities.

5. Network spillovers
Investment coordination problems: None identified.
Standards problems: VRML has developed as an open standard, and one interviewee's firm has been very active in the consortium defining open VRML standards. The interviewee believed that open source for VRML translators is the best way to push industry forward so that there becomes a critical mass of developers. The same principle could apply to 3-D visualization tools developed in VRML.

Other interviewees have argued that VRML might not be the best approach to 3-D.
Hardware-software coordination: Visualization tools may be limited by characteristics of graphics accelerators.
Software-software coordination: Conformity of applications to VRML standards. Availability of tools to build applications.
Existing installed base (as a barrier): No potential problems identified.
Future installed base (as a source of lock-in and monopolization): A critical mass of skills and applications in VRML, and in particular 3-D visualization tools, could inhibit emergence of better approaches.
Other sources of premature lock-in: None identified.
Economies of scale: need core of applications developers for approach to become more widespread, beyond very large firms.
Direct interactions between consumers (economies of consumption): None identified.
Synergies with other technologies (and economies of scope): collaborative workplaces.
Need for development of specialized uses: Visualization tools may be application-specific.
Other specialized use networks using this product: A strong possibility. e.g., auto-parts suppliers can serve two different manufacturers. An industry-wide process could lead to shared tools for visualizing auto parts and auto production processes.
Specialized use networks to which this product belongs: None identified

6. Barriers to development or commercialization
Capital availability: None identified.
Other special barriers: None identified

Interview 4: A Public, Shared Virtual World

1. Technology description

Technology name or description: A public, shared virtual world
Technology goal: Provide a VR space accessible to anyone, with a low entry-cost threshold
Technology technique: Several interrelated systems are needed:
1. a domain-name server or the equivalent, so that users can find each other
2. set of standards for describing a class of objects that can be created, and how they can move
3. editors or APIs (application programming interfaces) for creating the objects
4. hardware and software to run the objects and allow user interaction
5. hardware for manipulating and experiencing the objects (e.g., screens, HMDs=head-mounted devices, speakers, joysticks)

Current developmental status (stage, timeline, risk): Prototype systems have been demo-ed in laboratories. One developer claims ability to commercialize in under a year after funding is received. VRML is an available standard that hasn't taken off.
Selected leaders in field (experts, firms, laboratories): Silicon Graphics VRML; Netscape, Sun, Microsoft, IBM
Related, broader technologies: VR standards, systems, and APIs
Related, narrower technologies:
1. add-ins to the VR editor and standards
2. click-and-drop or other simple systems for user-designed avatars

2. Anticipated effects in immediate markets

Intended markets: will serve as location and medium for:
1. commercial VR sites for advertising, sales, and customer interface
2. multi-user game rooms, chatrooms, and recreational rooms
3. locations for collaborative work activities

Possible business models: None identified
Existing substitutes (negatively impacted): Existing websites are the main competitor. However, the system would tend to augment rather than replace existing ways of doing things on the web.
There will be negative effects on individuals with obsolescent web-page designer skills.
There may be negative effects on teleconferencing.
Nature of gain(s) to user (as compared with existing substitutes):
Dynamic versus primarily static websites
Primarily visually based versus primarily text-based medium
Interaction of multiple users in the same visual room
Possible sources of immersiveness: 3-D; mobility of user's point of view within VR space; wide view; high resolution
Likely limitations of technology in short-term:
1. A majority of potential consumers of VR space are severely limited by 28.8 Kbps bandwidth and Pentium 1 or lower processing power, and have no real-time output devices other than screens. Users will face a trade-off between resolution, number of independently moving objects, and degree of real-time responsiveness.
2. A majority of potential creators/providers of VR rooms are severely limited by programming ability; they need high-level editing languages. To a lesser extent, they may be limited by processing power of their own servers.
3. In many applications (such as chat rooms), consumers will also be creators/providers. so they will face both kinds of limitations. There may be a trade-off between level of the editing language and real-time responsiveness.

Consequently, we expect that initial implementations will involve:
1. limits on number of independent objects in a room (one informant claims 12 objects are feasible)
2. simplification of the visual objects
3. some degree of jerkiness
4. relatively low level editing languages, with a few high level features for manipulating pre-existing objects such as avatars.
5. problems with portability across output devices (e.g., screens versus HMDs).

6. problems with utilizing graphics accelerators, while delivering comparable products to user lacking them.
Additional desirable features:
1. injecting real-time views of real people into the VR space
2. real-time voice communication.

Potential for "inventing around": Substantial. Patents and copyrights will not be especially effective forms of protection.

Other future substitutes:
1. Improved teleconferencing.
2. Collaboration systems
3. Dedicated VR marketing systems

Other factors on monopolization potential:
1. If existing website addresses do not suffice and a new type of domain name server is needed (or can be enforced by the extant software; or enforced through software licensing) then the name server is a natural (or unnatural) monopoly.
2. The system will rely heavily on specific standards. These standards will give the first mover a strong initial advantage. A strong R&D program will be needed to maintain that advantage.
3. Microsoft, IBM, Intel, and Sun (VRML owners) are committed to existing hardware-software and have a joint motive to produce systems that require increasingly massive computing power. In the short run, they may have a very hard time changing strategies to deal with a computationally lean competitor that runs on legacy computers.

Other factors on intellectual property protection: If the domain names can be monopolized, then the software could be distributed as free ware.

National location: Mainly US. Blaxxun Interactive, Intel in Germany, and Active Worlds in UK are active.

Foreign government action: None identified

Other factors on timing of innovation: One informant estimated that 10,000 users would be needed to make the business self-sustaining; 100,000 to make it profitable and resistant to competitors; 10 years to make the system widely adopted similarly to where email is now.

3. Anticipated effects in related markets

Complementary products:
1. after market in avatars and art objects
2. editor add-ins
3. Internet services, computers, HMDs, screens, controllers

Potential for forced "tie-ins" of this product: Could be bundled in an operating system, such as windows

Potential for forced "tie-ins" to this product: Editor add-ins

Upstream products (inputs to production of this product): Computers, Internet services

Downstream products (uses this product as input to production): Could become practically ubiquitous in office activities, commerce, all forms of information processing

Antagonistic products: None identified

4. Knowledge spillovers

Potential spill-outs: Possible military applications were not explored

Potential spill-ins: Any developments in or using VR

5. Network spillovers

Investment coordination problems: Existence of VRML makes it hard to get backing for alternative approaches. Yet, VRML has not taken off because of its computational inefficiency.

Standards problems: VR representation standards are central.

Hardware-software coordination: None identified

Software-software coordination: Users won't adopt software until VR sites are available. Vendors won't develop VR sites until users are available.

Existing installed base (as a barrier): Programmers with web-page design skills under existing languages may resist change.

Future installed base (as a source of lock-in and monopolization):

1. VR sites, avatars and other art work will be designed using a specific system. There could be significant conversion costs for migrating to any new system.
2. Programmers will have an investment in learning the editing language.
3. Users could be reluctant to purchase any costly new software that was required.

Other sources of premature lock-in: Initially successful systems are likely to be computation- and bandwidth-efficient. As resource limitations relax over time, very different approaches may become optimal.

Economies of scale: There are the usual software economies of scale. There may be some *dis*economies of scale in the domain-name server technology; e.g., as the number of addresses gets larger, the length of the names gets longer, leading to higher overhead all around.

Direct interactions between consumers (economies of consumption): These will be very strong. This is a classic network problem, where no one visits the VR space unless others are there already.

Synergies with other technologies (and economies of scope): Interactions are possible with low-end animated content production for broadcast/cable.

Need for development of specialized uses: Specialized uses are likely but not essential to success.

Other specialized use networks using this product: None identified

Specialized use networks to which this product belongs:

1. particular forms of collaboration; e.g., medical diagnosis
2. very high resolution systems

6. Barriers to development or commercialization

Capital availability: None identified

Other special barriers: None identified

Interview 5: Non-Linear Digital Video Editing

1. Technology description

Technology name or description: Non-linear digital video editing.
Technology goal: Improve quality and reduce cost of video editing by:
1. reduce or eliminate delay time in accessing video segments that are separated in time sequence within a single source, or which come from multiple sources;
2. allow use of a wide variety digital processes to modify individual frames, or combine frames from different segments; and
3. potentially, at least, act as switch and conversion point for sources with multiple digital and/or analog formats.

Technology technique: In digital editing, the concept is that video is copied onto a hard disk, editing is done on hard disk, and (more often than not) results are written back to tape. In most cases, video is compressed as it is written to disk, and decompressed writing back out to tape. Furthermore, the actual edits usually take place on decompressed segments, so there are multiple compression/decompression steps.

Current developmental status (stage, timeline, risk): At commercialization stage. Non-linear editing devices now available from a number of companies. Price has come down from $100,000 a few years ago to $10-$20,000 today. As the price of disk space comes down, the line is moving between the linear editing that is done tape to tape and non-linear editing on disk.

There are still a number of technical barriers that affect cost-effectiveness. If cost were not an issue, long videos could simply be poured onto hard disks. In practice, disk space is still a long way from being cheap enough to do this. Furthermore, disk access needs to be extremely fast for non-compressed editing to be effective.

Most actual DV editing systems do some level of compression. Compression (generally) involves quality loss, and some time delay for implementing the compression algorithm. The interviewee is working on fast compression techniques.

Selected leaders in field (experts, firms, laboratories): Several firms, including Abbot Systems, Media 100, Radius, Pinnacle Systems, Fant Multimedia.

Related, broader technologies: Tools for video content creation**.**

Related, narrower technologies: Compression, disk I-O.

Cross-references: None identified

2. Anticipated effects in immediate markets

Intended markets: There are high end and lower end markets for the video editing devices and software.

High end: Broadcasters, esp. broadcast news, where there is a lot of money and a short time framework. Reporters come in with tapes from the field that must be edited very rapidly. Also at the high end are some advertisers and producers of multimedia games, who are attracted to non-linear editing for its relative advantages in introducing creative effects. For the high end of the market, There is a very high premium on video quality and there is a "cultural bias" towards choosing systems with low compression ratios. But working with low compression ratios can be difficult because it involves "pushing a lot of bits around," all of which take time.

Intermediate: Producers of TV shows, training videos, educational videos, etc. One interviewee thinks that the bulk of the units sold, and revenues generated, will be in this market. In this market, editing is done using quite a bit of compression. An example is a typical TV video produced by the BBC. BBC uses a high compression ratio, but quality is still high.

Low end: home users and other non-professionals (such as small businesses) who find video valuable. These people don't want to know about files sizes and compression ratios, they just want to get the job done. The analogy here is desk-top publishing.

Possible business models: market segmentation (degrees of quality). Firms do and will sell specialized hardware units, hardware plug-ins, and software.

Existing substitutes (negatively impacted): Tape to tape editing devices and skills.

Nature of gain(s) to user (as compared with existing substitutes): Quality of outcome. At low compression ratios, almost no quality loss from original. Fast editing turn-around. Ability to incorporate special effects.

Likely limitations of technology in short-term: In the short run, the trade off of compression-quality will continue to be a concern, and will keep high quality production expensive. Also, processor speed is still a limitation in implementing complex compression algorithms.
Ease of use and interoperability of equipment may be a limitation at lower ends of the market (see section on standards below).
Additional desirable features: A wide variety of special effect generators are available and others are under development.
Potential for "inventing around": For any given implementation of non-linear editing (including compression scheme) there will be alternative methods that other firms can devise for achieving the same goal. Currently, firms in this area have not had serious problems either inventing around or licensing technologies they want to use.
Other future substitutes: Tape to tape editing will continue to be used well into the future, especially on long video segments with few special effects.
Other factors on monopolization potential: See tie-ins (below)
Other factors on intellectual property protection: One interviewee claims that outside a few fundamental patents (that his firm either avoids or licenses), patenting has had only a secondary role in this industry because of the rapid pace of progress. One interviewee did not think that licensing or avoiding patents had been a problem to date.
National location: U.S. is not dominant. Important development taking place in U.S., Germany, other European nations, and Japan.
Foreign government action: None identified
Other factors on timing of innovation: None identified

3. Anticipated effects in related markets

Complementary products: Broader content production tools. Also processors, specialized chips for compression, plug-in devices to download video off source such as tape or storage device in digital camera. High resolution/ large screen/ flat screen monitors. Content production services.
Potential for forced "tie-ins" of this product: If interoperability continues to be a problem (see section on standards below) then turn-key solutions will probably be common, tying a customer to a single vendor for all components needed for video post-production.
At present, many editors are tied to a specific DV tape format; but the various formats are themselves proprietary.
Potential for forced "tie-ins" to this product: None identified
Upstream products (inputs to production of this product): Video compression algorithms. Input-output devices.
Downstream products (uses this product as input to production): Broadcasting, advertising, music videos, training videos, etc.
Antagonistic products: Traditional tape to tape editing systems.

4. Knowledge spillovers

Potential spill-outs: Research on video compression is being conducted by firms in the editing business, could have impacts on MPEG standards and transmission protocols. Compression could also be used in DV recordings.
Potential spill-ins: improvements in compression, disk I-o, etc. from other segments of DV and computer industry.

5. Network spillovers

Investment coordination problems: None identified
Standards problems: Standards are very important for the DV editing industry, and are at various stages of development. The internal image format used by most DV editing systems is MJPEG, which is not standardized, and so varies from manufacturer to manufacturer. This is not usually too big a problem, because the equipment writes out MPEG or MPEG2, which is standardized. It could be a problem, however, for using equipment from different manufacturers on the same internal files. A more serious problem is standards for devices that plug into the video editor– that get the video into the computer. The industry currently has problems of interoperability. According to one interviewee, when you buy CPUs from one vendor, software from another, and plug-in devices from another, it is difficult to get the system to work as a whole.

Progress on interoperability problems is taking place on two fronts. On one hand, some firms offer turn-key solutions. That is, the vendor solves the interoperability problems before the product gets to the consumer. On the other hand, standards are progressing, so that the problems may be less severe in the future.

Hardware-software coordination: See above

Software-software coordination: See above

Existing installed base (as a barrier): Because of interoperability problems, consumers may find themselves tied to particular vendors and turn-key systems. They may have difficulty upgrading equipment gradually as improvements appear in the market.

Future installed base (as a source of lock-in and monopolization): there are currently so many vendors and so many alternative approaches that monopolization will probably not be a problem in the short and medium run. Installed base will continue to be an obstacle to technical change.

Other sources of premature lock-in: None identified

Economies of scale: None identified

Direct interactions between consumers (economies of consumption): As DV editing products become more common at the low end (small business, non-professionals), it is likely that much informal training will go on within the workplace. Employees will probably teach skills to other employees, as is the case with current work-processing and graphics products.

Synergies with other technologies (and economies of scope): Improvements in editing approaches probably will be combined into a broader area of creation of video content, such as special effects.

Need for development of specialized uses: None identified

Other specialized use networks using this product: None identified

Specialized use networks to which this product belongs: video content creation has subareas for content broadcast versus news broadcast versus film special effects. Equipment standards can differ.

6. Barriers to development or commercialization

Capital availability: None identified

Other special barriers: None identified

Interview 6: Adaptive Network Delivery of Multimedia and 3-D Content

1. Technology description

Technology name or description: Adaptive network delivery of multimedia and 3-D content

Technology goal: Develop an optimal system of transmitting multimedia and 3-D content in a networked client/server environment which is characterized by an array of devices with differing capabilities and varying bandwidth connections. Clients envisioned extend from pervasive devices such as PDAs, to laptop computers, and workstations, and the connections might include wireless networks, telephone lines, and intra- or extra-nets.

Technology technique: Uses existing methods of transmission (e.g., VRML, Video plus range, MPEG) to transmit information. The goal is to develop methods to make optimal use of network resources to provide the highest quality transmission of content to clients with different capabilities. For example, if the client lacks 3-D acceleration, 3-D rendering might be done on the server and the resulting image transmitted. Another dimension of variation may concern the extent and method of compression to be used. Methods must also be devised to monitor network and client conditions and to switch transmission methods with minimum retransmission of data.

Current developmental status (stage, timeline, risk): Some specific applications are envisioned, and potential customers have been identified. Product development is likely within 12-24 months; testing with some customers is possible within 24-36 months.

Selected leaders in the field (experts, firms, laboratories): Silicon Graphics, IBM, Microsoft, University of Rostok (Germany), University of North Carolina

Related, broader technologies: Development of aware networks--that is networks in which devices communicate with each other about their capabilities, and current conditions, and network operations adapt in real time to this feedback.

Related, narrower technologies: None identified

Cross-references: None identified

2. Anticipated effects in immediate markets

Intended markets

1. Industrial maintenance: maintenance workers with wearable computers connected over a wireless network would be able to call up 3-D images or video demonstrating particular procedures, or assisting them in diagnosing and/or troubleshooting a problem.

2. CAD-CAM users. Core design groups would be able to share material they are developing over an intranet with legal, marketing, or other departments which may have less powerful equipment. Information could also be shared externally with key suppliers or customers needing to monitor design changes.

3. Multimedia content producers. As in 2, core producers may have access to more powerful computation equipment than others who need to monitor and track their work. The technology would make it easier to share the necessary information.

Possible business models: None identified

Existing substitutes (negatively impacted): Photographs, printouts, video, and other means of distribution can be used

Nature of gain(s) to user (as compared with existing substitutes): More timely, accurate, and higher quality information is available and is continually updated.

Likely limitations of technology in short-term:

1. Solutions are likely to be easier within known and controlled environments. Extending solutions to deal with a more open network in which the specific clients and their uses are not known in advance will be significantly more detailed.

2. There is a need for coordination with application programmers so that APIs (Application Program Interface) are available to plug into the system.

Additional desirable features:

Ability to monitor network conditions and client capabilities to make better use of resources.

Extension of these principles to the Internet in general.

Potential for "inventing around": Potential for inventing around any patents is high for some of basic components of the system. Nothing here is "rocket science" as far as transmission techniques are concerned, and methods are widely understood. On the other hand integrating the different techniques within a common framework is considerably more challenging, and will be much harder to replicate.

Other future substitutes: None identified
Other factors on monopolization potential: There will be first mover advantages because of the need to standardize APIs to conform to the system that is developed. System integration will also favor relatively large companies over small producers.
Other factors on intellectual property protection: Specific methods may be patentable.
National location: US developers seem most prominent, but there is some foreign work on this subject.
Foreign government action: None identified
Other factors on timing of innovation: None identified.

3. Anticipated effects in related markets
Complementary products: New methods of representing, transmitting, and rendering 3-D or multimedia content; Network services
Potential for forced "tie-ins" of this product: None identified.
Potential for forced "tie-ins" to this product: None identified.
Upstream products (inputs to production of this product): New types of clients and servers designed to run under this system.
Downstream products (uses this product as input to production): Content creation of 3-D and other multimedia
Antagonistic products: None identified.

4. Knowledge spillovers
Potential spill-outs:
1. Success in this field is likely to increase the ability to develop systems of transmitting complicated multimedia content over the Internet.
2. Success will also have positive impacts on the development of "aware" networks in which devices can communicate with each other about their capabilities and current conditions so that network services can be reallocated optimally.
Potential spill-ins: Development of better techniques for transmitting, rendering and displaying 3-D and multimedia content.

5. Network spillovers
Investment coordination problems: None identified
Standards problems: If standards for APIs are not developed it will slow or block progress on this technology.
Hardware-software coordination: None identified
Software-software coordination: None identified
Existing installed base (as a barrier): None identified
Future installed base (as a source of lock-in and monopolization): Once a particular set of standard interfaces with application programs are developed there will be a tendency to lock-in to these standards.
Other sources of premature lock-in: None identified.
Economies of scale: System standardization will enhance interactions across firms, as when information needs to be shared with suppliers or customers.
Direct interactions between consumers (economies of consumption): Specific networks that have adopted this technology could potentially communicate with each other.
Synergies with other technologies (and economies of scope): None identified.
Need for development of specialized uses: None identified
Other specialized use networks using this product: None identified.
Specialized use networks to which this product belongs: None identified.

6. Barriers to development or commercialization
Capital availability: Does not appear to be a major issue. A number of private sector actors are pursuing this research because they perceive commercial benefits. System integration factors may prevent small private companies from becoming players, however.
Other special barriers: None identified.

Interview 7: Video Conferencing

1. Technology description

Technology name or description: Video Conferencing
Technology goal: The goal is to deliver real-time video, with opportunities for collaboration.
Technology technique: Video is captured in a fixed setting, such as a conference room. Video is compressed and transmitted via Internet. Side channels for other collaboration may be opened. There are two basic approaches for producing the bit stream that is sent over the Internet: hardware and software. Hardware solutions (on a separate board) keep more of the processor free for other collaborations.
Current developmental status (stage, timeline, risk): The technology is currently being marketed. There are high end solutions - costing tens of thousands of dollars and requiring a room with a T1 line - and lower end solutions that address the needs of small business. The major risk is how fast this market will grow. Conferencing equipment is certainly NOT in every office that could potentially use it.
Selected leaders in field (experts, firms, laboratories): Intel, Picturetel, Apple, Georgia Tech, Sarnoff, UC Berkeley, UC Santa Barbara.
Related, broader technologies: Compression, video streaming, video telephony
Related, narrower technologies: Non identified
Cross-references: "non-professional" video production.

2. Anticipated effects in immediate markets

Intended markets: The product could be used by businesses and educational institutions of all sizes, including small business. It may penetrate into consumer markets.
Possible business models:
1. Specialized knowledge (say of compression techniques) developed by firms and laboratories. Large firms build new knowledge into their own produces, small firms and laboratories may licence technologies.
2. Firms build solutions that detect the type of system at the other end. When two people are using the same package, a proprietary standard may be employed; when the parties have different equipment, they default to a non-proprietary standard.
Existing substitutes (negatively impacted): Telephone conferencing; travel
Nature of gain(s) to user (as compared with existing substitutes):
1. Cost and time savings, as compared with travel.
2. More immediacy and more opportunity for collaboration as compared with telephone.
Likely limitations of technology in short-term: Most small businesses do not have enough bandwidth available to send really high-quality images in real time. So conferencing will not be "broadcast quality."
Additional desirable features: Ability to use side channels for collaboration (people can view the same spreadsheet, etc.)
Potential for "inventing around": High. Many possible solutions, some of which are pure software, some of which are hardware and software approaches.
Other future substitutes: None identified
Other factors on monopolization potential: None identified
Other factors on intellectual property protection: Patenting of compression, streaming, and other techniques developed as part of video conferencing packages.
National location: US shops are generally in the lead.
Foreign government action: None identified
Other factors on timing of innovation: None identified

3. Anticipated effects in related markets
Complementary products: video cameras, microphones, Internet services.
Potential for forced "tie-ins" of this product: Software and/or hardware could be bundled with computer.
Potential for forced "tie-ins" to this product: Special use cameras and microphones could come bundled with the software or hardware video conferencing solution.
Upstream products (inputs to production of this product): Computing hardware, telephone equipment, especially high-bandwidth.
Downstream products (uses this product as input to production): Service provision (legal, medical, etc. - conference could be a way of meeting with clients), most business that requires collaborative teamwork.
Antagonistic products: None identified

4. Knowledge spillovers
Potential spill-outs: Better compression techniques could have broad application. Techniques used for conferencing may be readily adaptable to video telephones.
Potential spill-ins: None identified

5. Network spillovers
Investment coordination problems: None identified
Standards problems: There is conflict between standards and proprietary solutions. Standards currently specify what the bit stream must look like, and specify the decoder. Implementers can develop encoders as they see fit. But for compatibility, the encoder is constrained by what can be decoded by the pre-defined decoder. Many firms think that they can achieve better quality with their own encoders AND decoders, "keeping it in the family" so to speak. The problem with this is that one company's product may no longer be able to speak to another company's product. One solution is a two-pass approach. The hardware/software would first detect whether the system on the other end was compatible with the proprietary codec. If so, the proprietary codec would be used. If not, the system would default to a non-proprietary standard.
Hardware-software coordination: Systems need to be able to talk with each other.
Software-software coordination: Systems need to be able to talk with each other.
Existing installed base (as a barrier): The current installed base makes conversion to a new standard feasible only if the new standard is compatible with the old.
Future installed base (as a source of lock-in and monopolization): None identified
Other sources of premature lock-in: None identified
Economies of scale: None identified
Direct interactions between consumers (economies of consumption): The more offices have video conferencing installed, the better substitute it will be for travel or telephone. Businesses will be able to count on other businesses have equipment available, just like today we count on them having e-mail available.
Synergies with other technologies (and economies of scope): None identified
Need for development of specialized uses: None identified
Other specialized use networks using this product: None identified
Specialized use networks to which this product belongs: None identified

6. Barriers to development or commercialization
Capital availability: None identified
Other special barriers: None identified

Interview 8: Home Digital Appliances

1. Technology description

Technology name or description: Home digital appliances (defined as the union of an electronic function other than computing with computers and/or digital networking).
Technology goal: Development of new consumer appliances to enable households to exploit opportunities created by the fusion of audio, video, and data streams. In particular these appliances will exploit the possibilities for non-linear viewing, interactive use of data, and the possibility to search for multimedia content at distant locations.
Technology technique: New appliances will arise out of the fusion between traditional home electronics products on the one hand, and computers/networking technologies on the other.
Current developmental status (stage, timeline, risk): Some products are already becoming available: e.g., set-top boxes for web-TV, Motorola's new "Blackbird" product which provides connections for DVD, games, HDTV, etc., and allows them to be played through a variety of display devices. There will be a continuing evolution of products over the next 5-10 years or more.
Selected leaders in field (experts, firms, laboratories): Home electronics, and computer hardware and software producers are significant actors in this field, along with producers and suppliers of multimedia content.
Related, broader technologies: Radio and television broadcasting, electronics manufactures, software, computers.
Related, narrower technologies: Data storage, data transmission, display technologies.
Cross-references: None identified

2. Anticipated effects in immediate markets

Intended markets:
Consumers of entertainment and/or information
Producers/suppliers of information/entertainment
Possible business models: None identified
Existing substitutes (negatively impacted): Existing methods of receiving, viewing, or using audio, video, and data streams; these include televisions, radios, personal computers, conventional telephones, video games, etc.
Nature of gain(s) to user (as compared with existing substitutes): Users will be able to exploit opportunities to customize multimedia streams, interact with them to obtain additional data, and view content non-linearly.
Likely limitations of technology in short-term: Providing robust, consistent, and simple to use appliances that are interoperable will require overcoming a variety of coordination and standardization problems. Usefulness in the short run will also be limited by the amount of bandwidth available for transmission of content, and the ability of devices to store and process this content. Interactivity will require storage of much of the content close to end users, possibly in the home. This will free up scarce network resources for searching and making links to individualized data sources.
Additional desirable features: (See likely limitations above). Interoperability between different appliances, different data paths, different content formats
Potential for "inventing around": High; Core components of these systems will be widely available. Opportunities for product differentiation and creation of added value will come in how these components are packaged and supported.

Other future substitutes: None identified
Other factors on monopolization potential: Hardware-software interactions and standardization create the potential for monopolization through the creation of proprietary methods of producing, transmitting, and using content streams. But these are opposed by pressures for market expansion and interoperability.
Other factors on intellectual property protection: Efforts to retain ownership of standards and embed them in vertical systems is counter to the technological trajectory created by the computer industry and the movement toward the transmission of digitized content. Nonetheless, existing electronics manufacturers, and content suppliers may seek to pursue this path.
National location: Products are likely to be developed for global markets, as existing national standards are broken down by the convergence of electronics and computing.
Foreign government action: None identified
Other factors on timing of innovation: None identified

3. Anticipated effects in related markets

Complementary products:

1. Display devices
2. Cameras,
3. Storage devices
4. Processors
5. Wired and wireless networks
6. content creators
7. content providers

Potential for forced "tie-ins" of this product: There is potential to bundle particular appliances (or packages of appliances) jointly with content, content formats, and networking services.

Potential for forced "tie-ins" to this product: See above.

Upstream products (inputs to production of this product):

Multimedia and data content for use in digital appliances

Hardware for appliances (networks, storage devices, processors, displays)

Software to run appliances

Networks for content delivery.

Downstream products (uses this product as input to production): Authoring tools to allow home production of content or manipulation of content.

Antagonistic products: Existing home electronics devices.

4. Knowledge spillovers

Potential spill-outs: None identified

Potential spill-ins: Digital appliances will benefit from advances in computer hardware and software.

5. Network spillovers

Investment coordination problems: These are a fairly significant problem as long as key players–e.g., in broadcasting, and conventional electronics devices–persist in following an older model of vertical separation of products, and end-to-end standardization, such as is embodied in current TV transmission methods.

There is also a need for investment in content creation that takes advantage of potential functionality of new appliances. Investment in creating content depends on the existence of appliances capable of using it.

Standards problems: There is the need to develop a new architecture of standards, that allow progressive expansion of functionality through new plug-in applications. Increasing processing power makes it easier to use general purpose devices and easily modified software, rather than special purpose hardware. But a new system of standards, analogous to those that organize the Internet is needed to allow the evolution of digital appliances.

In addition there are issues of intellectual property protection that need to be resolved. Content creators are reluctant to provide their product in settings where it can be easily reproduced and altered without control. Methods of tracking and charging for the use of content will need to be developed to facilitate content creation and supply.

Hardware-software coordination: There is a need for coordination between devices and content production.

Software-Software coordination: None identified

Existing installed base (as a barrier): Probably not a problem. There will be a market for adapters–e.g., set-top boxes–that enable existing hardware to utilize new streams of content.

Future installed base (as a source of lock-in and monopolization): Not identified as a significant problem.

Other sources of premature lock-in: Not identified as a significant problem.

Economies of scale: Appliances will need to be produced in large volumes to meet consumer market price points.

Direct interactions between consumers (economies of consumption): None identified.

Synergies with other technologies (and economies of scope): Possible synergy between content creation and appliances. Because of interaction between these two areas, there will be incentives for suppliers to integrate these activities.

Need for development of specialized uses: None identified

Other specialized use networks using this product: None identified

Specialized use networks to which this product belongs: None identified

6. Barriers to development or commercialization

Capital availability: This does not appear to be a problem

Other special barriers: Bandwidth will continue to constrain development for some time. As long as bandwidth is expensive, broadcasting will be used for mass markets. Specialized data will require more expensive methods of communication. There will continue to be a cost differential between cheap downstream broadcast transmission and relatively more costly upstream communications from consumers.

Interview 9: Authoring Tool that Provides Single Creative Space

1. Technology description

Technology name or description: "One Creative Application." An authoring tool that provides a single creative space for working with images, image streams, and sound.

Technology goal: To integrate pixel based and geometry based approaches to image creation and manipulation within a single application that makes it unnecessary for users to understand the distinction between these approaches to representing visual images.

Technology technique: Employs the α-channel concept which adds a fourth piece of information to each pixel. In addition to red, green, and blue values, the α-channel contains a value for transparency (ranging from 0 for completely transparent, to 1 for completely opaque).

Current developmental status (stage, timeline, risk): Microsoft has just released a commercial application employing this technique: Photodraw 2000. This allows manipulation of 2-D still images. Further development would allow manipulation of 3-D images, addition of a time dimension to create video streams, and presumably also allow greater integration of sound with images.

Selected leaders in field (experts, firms, laboratories): Others at Microsoft are exploring this topic, as are people at Pixar.

Related, broader technologies: VR and DV editing software

Related, narrower technologies: None identified

Cross-references: None identified

2. Anticipated effects in immediate markets

Intended markets: Primarily consumer market. This product is designed to make it easy for individuals lacking training or prior experience manipulating image-based data to work with them. It is analogous in this sense to earlier developments in desktop publishing.

Possible business models: None identified

Existing substitutes (negatively impacted): There are a variety of professional applications that are used to manipulate images at the moment–e.g., Adobe Illustrator, and Adobe Photoshop.

Nature of gain(s) to user (as compared with existing substitutes): Existing products are designed either for geometry or pixel based representations, are poorly integrated with each other, and don't work well with other computer applications. "One Creative Application" will merge them and conceal the problems of integrating these different approaches. It will conceal many other technical issues like color representation that consumers are unlikely to understand. Finally it will make it easy to export the results to other applications–spreadsheet, wordprocessor, presentation software, or web publishing, for example.

Professional users will continue to want greater control, and probably won't abandon professional applications. On the other hand, the size of this market will shrink as the capacity of home systems expands.

Likely limitations of technology in short-term: Processing power, storage, and input and output devices will be the major constraints. This is an Operating System sized application, and it will make heavy demands on existing hardware, but Moore's Law suggests that within 5-10 years, these capabilities will be much more widely available.

Additional desirable features:

Ease of use is crucial for wide acceptance.

Extension to video streams and multimedia authoring are important extensions.

Elimination of the rectangular constraint on images. Images need to be conceived of and created in more flexible formats.

Potential for "inventing around": High. The fundamental insight is in the public domain and is well understood.

Other future substitutes: It is highly likely that other software developers will introduce competing products.

Other factors on monopolization potential: None identified.

Other factors on intellectual property protection: The user interface, and the packaging of the application will be crucial to protecting intellectual property. Ease of use through a common interface for example will be important as this product will be bundled with other productivity applications as part of future versions of MS Office. The precise

features that the package provides and how it provides them will also be an avenue for product differentiation. Particular realizations of the product can be patented.
National location: Not aware of significant work outside the U.S.
Foreign government action: None identified.
Other factors on timing of innovation: None identified.

3. Anticipated effects in related markets
Complementary products:
VR and editing software
Other productivity software
Display devices
Input devices (cameras, scanners, etc.)
Storage devices
RAM
Network bandwidth, for transmission of multimedia
Potential for forced "tie-ins" of this product: Product is likely to be bundled with other software applications.
Potential for forced "tie-ins" to this product: Product is likely to be bundled with other software applications.
Upstream products (inputs to production of this product): Storage devices, RAM, input devices and displays, bandwidth for communication.
Downstream products (uses this product as input to production): Multimedia authoring, web page creation.
Antagonistic products: Professional image editing software. Special purpose imaging devices, such as digital photography or video cameras that incorporate their own image processing software rather than relying on a general purpose computer.

4. Knowledge spillovers
Potential spill-outs: Development will reveal a good deal about what uses people will find for the new tools they are being provided, and how they want to interact with them.
Techniques may be applicable in other areas, like medical imaging.
Potential spill-ins: Research on user interfaces, and how consumers interact with software applications will increase the ability to design products that do what people want to be able to do.

5. Network spillovers
Investment coordination problems: None identified
Standards problems: Sharing multimedia content poses potential standards problems, but they are likely to be addressed by the market. Regulatory imposition of standards is likely to slow progress rather than facilitate it.
Hardware-software coordination: There are potential issues here, but again the market is likely to resolve these.
Software-software coordination: None identified
Existing installed base (as a barrier): Not compatible with existing DV and image editing software.
Future installed base (as a source of lock-in and monopolization): Possible issue. Integration with existing software products will provide a large user base that may convey market power.
Other sources of premature lock-in: Unlikely because barriers to entry by new and better products are not large.
Economies of scale: None identified.
Direct interactions between consumers (economies of consumption): This will be important. Ability to share multimedia content will depend on using a common platform, or providing conversion mechanisms between competing products.
Synergies with other technologies (and economies of scope): Significant, because a single interface will mean only one learning curve, rather than many. It will also be easy to move products seamlessly between different applications.
Need for development of specialized uses: None identified
Other specialized use networks using this product: None identified
Specialized use networks to which this product belongs: None identified

6. Barriers to development or commercialization

Capital availability: Not a constraint.

Other special barriers: None identified

Interview 10: Video Production for the Non-Professional

1. Technology description

Technology name or description: Video production for the non-professional. The main subject discussed by our interviewee was development of training programs.
Technology goal: To integrate tools for creating multi-media products to support learning, training, and other needs.
Technology technique: This is not so much a separate technology as an approach to integrating technologies that have uses in other areas of DV. The following contribute to successful development and deployment of training videos by non-professionals:
1. Video capture tools. Tools for getting video onto the computer.
2. Content creation tools. Easy-to-use content creation tools enable people who have the knowledge of the subject area to participate in the creation of the training program. Content creators need to be able to sequence, title, and edit video without becoming professional video makers.
3. ADVANCED content creation tools. To keep the students interested, content will need to be "compelling." The introduction of 3-D images and special effects can help to focus the student's attention. Furthermore, 3-D adds realism in many situations (like training on the factory floor). Instead of just looking at a two dimensional slice of a machinery part, the student (say an assembly worker) could get more of a feel for how parts fix together.
4. Delivery mechanisms. The Internet plays two important roles in training programs. For some training applications, it is essential that information distributed rapidly. For example, a company with several factories around the country may discover a problem with a part and may want to show workers how get to fix things immediately. In other applications, rapid feedback is important. A student working over the Internet can have her knowledge and understanding tested interactively.
Current developmental status (stage, timeline, risk): The individual components needed for instruction and the development of training programs are fairly well developed. What are needed and are currently under development are easy to use tools for the non-professional. It is not completely obvious what it means to be "easy to use." Some developers are doing psychological studies to see what people actually do when confronted with a new software products. Some developers are working on creating "task" oriented rather than menu oriented interfaces, leading users through the process of creating a video. The main risk is that even "easy to use" will be too hard for a broad segment of consumers.
Selected leaders in field (experts, firms, laboratories): [omitted to protect confidentiality of respondent, but includes both large and small firms.]
Related, broader technologies: Video compression and decompression, 3-D authoring tools, video capture, digitization.
Related, narrower technologies: none identified.
Cross-references: 3-D authoring, Video conferencing. see interview 9.

2. Anticipated effects in immediate markets

Intended markets: The approach is marketed to the non-professional, that is, anyone who uses a camcorder today. Business training uses are likely to be first (and are in fact happening). As software and hardware become better integrated, the technology will move to a broader consumer market.
Possible business models:
1. Large and small software firms integrate and improve upon known technologies. Improvements may include better compression techniques, better user interfaces, and better use of computer processor speed.
2. Possible bundling of software with hardware, including computers and camcorders.
3. Possible sales of training programs developed using such software, either on disk or on-line.
Existing substitutes (negatively impacted): Software for production of professional quality video, profession video producers.
Nature of gain(s) to user (as compared with existing substitutes):
1.Cost reductions

2. Flexibility. Training videos could be produced and distributed when needed. For example, suppose that a firm with several factories nationwide is experiencing a problem with a part. A video showing assembly workers how to fix the problem could be made and distributed on-line within hours.
3. Better production values for “home movie” type videos.
Likely limitations of technology in short-term: Ease of use. Disk space and processor power constraints are much less important now than they were a year or two ago.
Additional desirable features: None identified
Potential for “inventing around”: medium. There are many possible ways that basic techniques could be integrated. However, successful integration requires specialized knowledge how the consumer thinks and what is actually easy, in addition to technical knowledge.
Other future substitutes: None identified
Other factors on monopolization potential: None identified
Other factors on intellectual property protection: “Keeping ahead” is likely to be the main form of protection. Patents are important when a firm develops a feature unique to its software. Underlying techniques such as motion tracking are patented.
National location: US generally in the lead. Some underlying technologies were developed in Israel (motion tracking) and England.
Foreign government action: Israel (military)
Other factors on timing of innovation: None identified

3. Anticipated effects in related markets
Complementary products: Video cameras, fast processors and disk space, hardware devices to move video from camera to computer.
Potential for forced “tie-ins” of this product: Software could be bundled with hardware.
Potential for forced “tie-ins” to this product: None identified

Upstream products (inputs to production of this product): Compression technologies, CODECs, 3-D rendering technologies.
Downstream products (uses this product as input to production):
Video content creation and distribution, training programs, manufacturing.
Antagonistic products: None identified

4. Knowledge spillovers
Potential spill-outs: Work on ease of use could result in better interfaces for many types of software. Improvements in compression, animation, etc. developed while working on such software could have broader applications.
Potential spill-ins: None identified

5. Network spillovers
Investment coordination problems: None identified
Standards problems: The major standards problems involve the camcorder-computer interface. There are de facto standards driven by the giant companies, but sometimes these are not the best solutions technically or the most timely solutions.
Hardware-software coordination: Software needs to work with video input devices.
Software-software coordination: None identified
Existing installed base (as a barrier): None identified
Future installed base (as a source of lock-in and monopolization): Software-hardware bundling could make it difficult for start-up firms to enter market.
Other sources of premature lock-in: None identified
Economies of scale: Slight, other than that research costs are spread across a wider base, the larger the market.
Direct interactions between consumers (economies of consumption): None identified

Synergies with other technologies (and economies of scope): Synergies with component technologies. Improvements to basic technologies may be discovered.
Need for development of specialized uses: None identified
Other specialized use networks using this product: None identified
Specialized use networks to which this product belongs: None identified

6. Barriers to development or commercialization
Capital availability: None identified
Other special barriers: None identified

Interview 11: Metadata Architecture

1. Technology description

Technology name or description: metadata architecture

Technology goal: Establish a framework for analyzing videos and creating descriptive data (metadata); the descriptive data will then be used to support DV management activities such as indexing, cataloging, storage, retrieval, searching (internally to the video segment), semi-automated editing, broadcast program management.

Technology technique: Products could differ along six main dimensions:

1. the input interfaces may accept a variety of video formats
2. the video analyzers/metadata creators may be proprietary and hardwired, or they may be plug-ins
3. the internal process of the main driver could differ in algorithm (leading to differences in speed, reliability, adaptability)
4. the metadata output may be hardwired and integrated with particular types of systems, or the main driver may it self be a free-standing plug-in to other downstream systems.
5. output metadata format could have a variety of data-structures. However, standard structures will likely consist in multiple data tracks laid down along a common frame-accurate time line together with the underlying video segment.
6. the application programming interface (API) and/or software developer's kit (for plug-in developers) could differ in features and functionality.

Current developmental status (stage, timeline, risk): Virage has a product being marketed and in use. Other companies have announced products. There may be additional development in architectures. Once the architectures become standardized, there will be on-going development both in what kinds of metadata the plug-ins can generate and in what algorithms they use and how well they do it. It is likely that the architectures themselves will be very important, widely used, and reasonably standardized. The plug-ins (or their hard-wired equivalents) are likely to be highly competitive and rapidly changing for some period of time.

Selected leaders in field (experts, firms, laboratories): Virage, Ramesh Jain (UC-San Diego), Excalibur RetrievalWare, ISLIP Media at Carnegie-Mellon

Related, broader technologies:

1. indexing, cataloging, storage, retrieval, searching (internally to the video segment), and editing.
2. plug-in architectures.

Related, narrower technologies: particular video analyzers and metadata creators

Cross-references: None identified

2. Anticipated effects in immediate markets

Intended markets:

1. video and film asset management systems
2. TV news editing systems; video editing systems in general
3. video database systems
4. video-info on demand systems
5. research systems using video databases

Possible business models: None identified

Existing substitutes (negatively impacted):

1. large-scale asset management systems currently consist in manual retrieval of lightly documented film and video segments.
2. video media will become more competitive with print media.
3. non-linear editing systems will gain increased advantage over linear editing systems

Nature of gain(s) to user (as compared with existing substitutes): Vastly higher speed, lower cost, improved accuracy, wider scope, and automated control of DV editing and management tasks.

Available plug-ins include: automated story-board with key frames; audio classifier; color bar/black screen/static detection; SMPTE time code extraction; closed-caption extraction; OCR in visual frame; English speech recognition (70% accuracy); speaker ID.

Likely limitations of technology in short-term:

1. A key trade-off is between real-time versus rendered data-analysis. Real-time expands the possible applications but limits algorithms, expands hardware demands, and reduces quality and number of useable plug-ins available under technologies current at each point in time.
2. "Real time" can be defined as "with a fixed maximum computational delay." 15 seconds might be a reasonable delay. There may be competition to reduce the delay.
3. System usefulness will be limited by video database storage costs and access times.
4. There could be a trade-off between costs of storing complete sets of metadata versus time delay from recalculating it at the time of search or retrieval.

Additional desirable features: Additional plug-ins or meta-data types and tracks, such as: human face ID; gender ID; foreign language ID; "lie" (voice stress) detector; adding GPS data; adding sales data; ID types of scenes or actions

Potential for "inventing around": High. The interface standards are open; the product consists mainly in software functions, which can be replicated without violating copyrights.

Other future substitutes: It is possible to market metadata creation services rather than software; but this commercial model seems unpromising.

Other factors on monopolization potential: First mover advantage is likely to be high. A reputation for high reliability as demonstrated by wide-spread use will be absolutely essential in production environments.

Other factors on intellectual property protection: Reverse engineering will be nearly as expensive as original development because the product is very complex and implements trade secrets.

National location: Potential competitors exist in Netherlands/Europe (Tecmath's Euromedia), Israel (Media Access Technologies Ltd.), Australia (CSIRO's Mediaware), Switzerland (Excalibur RetrievalWare)

Foreign government action: None identified

Other factors on timing of innovation: None identified

3. Anticipated effects in related markets

Complementary products: This product is complementary to virtually all types of DV editing, management and manipulation systems and services, and also complementary to many forms of DV creation and delivery.

Potential for forced "tie-ins" of this product: This product could be bundled with virtually any product that uses meta-data as an input.

Potential for forced "tie-ins" to this product: Plug-in architecture tends to preclude forced tie-ins. Other architectures tend to require forced tie-ins of analyzer modules.

Upstream products (inputs to production of this product): Hardware components and software media to convey functionality for metadata calculations.

Downstream products (uses this product as input to production): Content creation, broadcasting, narrow-casting, public databases, information-on-demand; practically every form of content management and distribution

Antagonistic products: None identified

4. Knowledge spillovers

Potential spill-outs:

Plug-in architectures

Many DV-related artificial intelligence systems

Scientific and analytic data modeling and analysis, especially pattern recognition and trend analysis on time-series data.

Potential spill-ins: Adobe Photo-shop; other plug-in architectures

5. Network spillovers

Investment coordination problems: None identified

Standards problems: A plug-in architecture constitutes a de-facto standard. Private creation of public standards could in theory lead to socially sub-optimal design, because of incentives for the creator to maintain commercial control. However, one consultant claims that metadata format standards by themselves do not have any strong technical implications. Plug-in interfaces, on the other hand, could have technical implications.

Hardware-software coordination: Speed limitations of architecture and plug-ins could lead to parallel-processing solutions requiring specific hardware designs.
Software-software coordination: Plug-ins have to fit the architecture.
Existing installed base (as a barrier): Existing video databases could need adaptation for most efficient use.
Future installed base (as a source of lock-in and monopolization): Depends partly on architecture. Plug-in interfaces would be hard to change without outmoding existing plugins. If a library of pre-calculated metadata is created, then major changes in format would be expensive. Also, downstream programs will require specific metadata formats.
Other sources of premature lock-in: Architectures may need to change in the future to become more integrated with MPEG.
Economies of scale: None identified
Direct interactions between consumers (economies of consumption): None identified
Synergies with other technologies (and economies of scope): Synergies exist with nearly all aspects of the DV economy.
Need for development of specialized uses: None identified
Other specialized use networks using this product:
1. Specialized plug-ins could be developed and shared within a user group.
2. Specialized medical applications could be developed.

Specialized use networks to which this product belongs: None identified

6. Barriers to development or commercialization
Capital availability: Capital does not appear to be a constraint.
Other special barriers: None identified

Interview 12: Interactive Digital Video for Distance Learning

1. Technology description

Technology name or description: Interactive digital video for distance learning and other applications.

Technology goal: There are may potential customized and interactive applications of DV, including: (at the very low end of interactivity) multicasting, where a viewer selects a particular TV-like video stream to view, through (at the high end of interactivity) video conferencing where everyone sees everyone else. "Interactive TV" is somewhere in the middle. The idea is that a fairly high quality video stream will be sent to interested users, and that there will be side-channels for feedback-interaction. The number of people who will be involved is generally greater than for a video conference, and the people may be scattered geographically.

An important application is distance learning, with two way communications. The goal is distribution of video to users needs and purposes, in contrast with passive viewing. This report focuses on the more interactive applications.

Technology technique: Distribute video to particular users, and allow 2-way communication. There exist solutions for small-group video conferencing using ITU H.320 systems. For larger settings, such as distance education, technologies are under development to multicast video to users, with some feedback options. These systems are based on Internet M-Bone technologies

Current developmental status (stage, timeline, risk): For interactive TV: The respondent and his institution have been working on building an interactive television distribution system based on Internet M-Bone technology For the last 4 years, they have been broadcasting a regularly scheduled seminar world wide on the Internet, watched by as many as 200 people. Issues still on the table are getting higher quality in production values into the system, which may require desktop processing of video effects by the person who receives the video stream. Additionally, they are also working on getting side channels so that people can actually engage in side discussions during the session. There have been serious technical problems in getting the network, the computers, and the software to work together.

Put another way, technologies for video-conferencing are well developed. Lecture-style distance learning with no interaction, can be done just like any other TV broadcast, limited only by bandwidth and by the cooperation of Internet service providers. What still needs to be done is to make video more interactive.

Selected leaders in field (experts, firms, laboratories): Xerox Park, Bell Labs, Lawrence, UC-Berkeley Labs, University College London, USC Information Sciences Institute.

Related, broader technologies: Multicasting, compression, TV broadcasting

Related, narrower technologies: Video effects processing, content creation tools, video conferencing.

Cross-references: None identified

2. Anticipated effects in immediate markets

Intended markets: Distance learning: Current solutions (outside of small video-conference type settings) do not allow sufficient interactivity, nor do they scale to large numbers of participants at geographically dispersed locations. The distance learning model could also be applied to almost any content area. A group of interested people could receive a broadcast and at the same time interact. Examples would be political organizations, special interest groups, and companies providing training sessions.

Possible business models: Development of software by universities and research labs. Licensing of software by universities and government labs. Development of packaged solutions by private sector.

Existing substitutes (negatively impacted): Traditional broadcast TV

Nature of gain(s) to user (as compared with existing substitutes): Ability to take classes without traveling. Increased opportunities for interaction. Ability for firms to train with much more interactivity than a training film, without having to send a trainer to each location where personnel need training.

Likely limitations of technology in short-term: Difficulties in getting software, hardware, network, to all work together. This will limit uses to experimental settings (like universities) in the very short run.

Additional desirable features:

1. Interoperability is essential.
2. Improved content creation, with ability to process special effects on desktop, is desirable.

Potential for "inventing around": What is needed here is not so much new technological breakthroughs, but rather combination and coordination of existing and developing technologies to meet user needs. There are probably many solutions to the problem, so potential to invent around is high.
Other future substitutes: None identified
Other factors on monopolization potential: Specialized knowledge required, but market likely to be competitive.
Other factors on intellectual property protection: The main protection consists in trade secrets and know-how. There may be patents are component parts, such as video compression schemes used in broadcast, that may need to be licenced.
National location: US in lead. European presence starting to be felt. Asia and Australia may also be players in the future. US is still the leader in the fundamental technology.
Foreign government action: None identified
Other factors on timing of innovation: None identified

3. Anticipated effects in related markets
Complementary products: Networking, content creation, other DV communications.
Potential for forced "tie-ins" of this product: There may be turn-key solutions that tie together several products-approaches.
Potential for forced "tie-ins" to this product: None identified
Upstream products (inputs to production of this product): Equipment components, compression software, video watermarking, multi-cast technologies
Downstream products (uses this product as input to production): Education and training courses. Conventions (could use as a segment).
Antagonistic products: Broadcast TV, conventional education and training.

4. Knowledge spillovers
Potential spill-outs: Improved content creation tools, improved desktop processing of DV, improved two-way communications to be used more generally.
Potential spill-ins: Improved transmission technologies.

5. Network spillovers
Investment coordination problems: None identified
Standards problems: There is tension between organizations trying to set and control a standard versus experimenting with new technologies to try and understand appropriate standards groups (risk of premature lock-in). At certain levels the standards have been developed in other areas they haven't. For example, delivery of audio and video packets on the Internet is defined, it's called RTP. There are payload formats for RTP which can be defined for your favorite CODEC, whatever your audio or video coda is you can define them and put those in. There are some problems getting the large software firms to actually use these standards, because the elephants want to own and control their own standards. So there is a problem getting general adoption of protocols that have been developed.

Better protocols for doing collaboration and control for different specific applications. The problem is that there are some standards established but they are pretty rigid for particular applications. For example, there are standards for video-conferencing (H.320). They handle a particular kind of conferencing set-up, on the order of five to ten people doing collaboration, but the protocols do not scale, or are not open enough to allow groups to do other things.
Hardware-software coordination: Getting systems to work as a whole is a difficult problem involving both hardware and software.
Software-software coordination: None identified
Existing installed base (as a barrier): Current pricing and delivery mechanisms of Internet Service Providers may hinder multicasting. Multi-cast protocols and management are still immature.
Future installed base (as a source of lock-in and monopolization): Standardization may lock in approaches that are too rigid and that don't allow sufficient interactivity among large numbers of people.
Other sources of premature lock-in: None identified
Economies of scale: None identified.

Direct interactions between consumers (economies of consumption): There will need to be sufficiently many people participation in each interactive session for the interaction to be meaningful to all involved.
Synergies with other technologies (and economies of scope): Improved compression will allow cheaper-faster broadcast. Improved video capture (multiple cameras, etc) may give a better sense of presence in interactive
Need for development of specialized uses: None identified
Other specialized use networks using this product: None identified
Specialized use networks to which this product belongs: None identified

6. Barriers to development or commercialization
Capital availability: None identified
Other special barriers: Difficulty in coordination.

Interview 13: Generalized 3-D Object Recognition

1. Technology description

Technology name or description: Generalized computer recognition of 3-D objects
Technology goal: To automate various aspects of the interpretation of visual data so that images can be matched to particular objects; either so that images can be identified or so that images matching certain criteria can be retrieved from a visual database. One particular aspect of this is to be able to correctly identify the same object when it is depicted from different angles or under different lighting conditions.
Technology technique: Develop a general model equivalent to:
1. describe a 3-D object
2. model how it is projected into 2-dimensions
3. identify discrete objects in a given image, and
4. match an object in the given image with a projected image.

Current developmental status (stage, timeline, risk): This is basic research that is not expected to generate commercial applications within the next 5-7 years. Solutions to specific problems may be commercialized sooner, but solution of the general problem will not occur soon.
Selected leaders in field (experts, firms, laboratories): Microsoft; David Sarnoff Laboratory; David Kriegman at University of Illinois; David Forsyth and Jitendra Malik at U.C. Berkeley
Related, broader technologies: Computer vision, robot vision.
Related, narrower technologies: Identification of particular types of objects–e.g., faces. 2-D object recognition. Motion analysis.
Cross-references: interview 2; interview 10; interview 15

2. Anticipated effects in immediate markets

Intended markets: very widespread. examples include:
Retrieval of images/videos from image or video databases; object-oriented databases; asset management.
Industrial inspection, process control
Security and surveillance systems, military intelligence and targeting
Object tracking in real time
Human-Computer Interaction
Graphics programs
Creating metadata
Medical diagnosis.
Possible business models: technology could be licensed for specific uses. The uses are too broad for the technology owner to exploit all of them.
Existing substitutes (negatively impacted): For the most part existing approaches rely largely on human beings to sort, and analyze images. Computer methods are being developed for matching certain classes of objects, and for classifying images in various generic or statistical ways.
Nature of gain(s) to user (as compared with existing substitutes): Lower cost and higher speed compared to existing methods of cataloging and identifying images; wider application of image recognition.
Possible negative gains: loss of individual privacy.
Likely limitations of technology in short-term: Ability to identify objects is limited. Full solutions are possible only for narrowly defined problems. More general problems can only be solved partially.
Additional desirable features:
1. Computational speed is important. real time recognition would have much wider uses than delayed recognition, e.g., in security systems; in searching DV databases for on-line queries.
2. The user interface will include an object-description language or some other input interface. The scope, convenience and intuitive nature of this interface will have large effects on the usefulness of general-purpose systems. In the case of applied systems, this will not be as critical.
3. There is a difference between recognizing a particular object (e.g. George Washington), and a generic class of objects (e.g. formally dressed men). both problems are important.

4. There is another difference between static images and moving images.
5. Multispectral analysis may be a specialized case.
Potential for "inventing around": Some approaches and specific implementations may be patented, but much of the work here creates basic scientific knowledge that will be a public good. Protection will probably depend more on trade secrets than on patents.
Other future substitutes:
1. systems specialized to particular classes of objects will continue to be developed, and could continue to have a competitive edge in particular applications. If the class of object is already known, then computational speed can be significantly enhanced.
2. learning based systems. Rather than constructing general models of vision, these systems build up an ability to identify objects experientially. The accretion of specific solutions will expand the scope of problems that can be dealt with in this way.
3. systems that use ancillary information such as functional use of objects, or general background knowledge about classes of objects, to solve recognition problems .
Other factors on monopolization potential: None identified
Other factors on intellectual property protection: None identified
National location: majority of activity appears to be in the US. Some activity in the united Kingdom.
Foreign government action: University research funding under science programs, as in the US.
Other factors on timing of innovation: Greater computational power is a major factor influencing the timing of innovation. Expansion of computational power has greatly expanded the size and scope of problems that can be addressed.

Limitations on funding for research could be delaying innovation.

3. Anticipated effects in related markets
Complementary products: Development of better object recognition techniques will enhance demand for products such as digital cameras, scanners and other input devices which create digital images, as well as applications that use digital images.

Computers are also complementary because of their increased usefulness
Potential for forced "tie-ins" of this product: None identified
Potential for forced "tie-ins" to this product: None identified
Upstream products (inputs to production of this product): Digital cameras, scanners, etc. that create images, computers, DV and image compression technologies.
Downstream products (uses this product as input to production):
Image retrieval systems based on object recognition: Internet search engines, cataloging and indexing systems, synopsis systems.
Image databases
Management of physical goods: Security systems, inventory and tracking systems, maintenance operations
Management of production: Robotics, inspection/quality control
Military and surveillance systems
Antagonistic products: None identified

4. Knowledge spillovers
Potential spill-outs:
Virtual reality
3-D modeling,
Image compression technologies; DV compression
Robotics
Medical imaging and analysis of medical images
Object-based editing systems.
Potential spill-ins:
Video compression (MPEG4).

Other areas of computer vision research–perceptual grouping, motion recognition; solutions to specific object recognition problems.

5. Network spillovers

Investment coordination problems: None identified

Standards problems: use of object recognition in DV compression would require standards.

Hardware-software coordination: None identified

Software-software coordination: None identified

Existing installed base (as a barrier): None identified

Future installed base (as a source of lock-in and monopolization): None identified

Other sources of premature lock-in: If DV compression becomes standardized too soon, then it may be difficult to introduce new forms of compression based on object recognition.

Economies of scale: None identified

Direct interactions between consumers (economies of consumption): None identified

Synergies with other technologies (and economies of scope): Image compression could both be based on and feed into object recognition systems. DV compression could take advantage of object recognition, if human perceptual models showed that certain objects were more sensitive than others. If DV compression is oriented to objects, then real-time object recognition in the compressed domain will be feasible at a lower cost.

Need for development of specialized uses: even if very general techniques are eventually developed, they will need to be commercialized first in restricted forms in specialized applications.

Other specialized use networks using this product: None identified

Specialized use networks to which this product belongs: None identified

6. Barriers to development or commercialization

Capital availability: Funding seems increasingly focused on research for narrowly defined image recognition problems, rather than more general approaches. Limited funding may be impeding development. This kind of knowledge tends to be a public good, and the research horizon is relatively distant, so that commercial investments are limited.

Other special barriers: None identified

Interview 14: Shared Virtual Reality Servers

1. Technology description

Technology name or description: Shared virtual reality servers
Technology goal: Provide a virtual meeting place on the Internet with manipulable objects and avatars.
Technology technique: Centralized servers keep track of status of a 3-D virtual space and send out messages to users in VRML to describe its initial state or changes. Distributed processing recreates the space, or a 2-D version, depending on local processing power. APIs are needed for developing sites and applications.
Current developmental status (stage, timeline, risk): Leading vendor has between 100 and 1000 VR sites under license. User software has been distributed to roughly 1 million individuals. Vendor's expectations are: 1K to 10K sites in 3 years, 10K to 100K sites in 5-7 years, or perhaps explosive exponential growth could be reached at an earlier point in time. The growth rate will depend heavily on the rate at which Internet users acquire Pentium II machines with graphics accelerators, or higher powered equipment.
Selected leaders in field (experts, firms, laboratories): Blaxxun Interactive, de Groot
Related, broader technologies: VR modeling languages; VR servers; client-server systems
Related, narrower technologies: Hybrid composition of natural and artificial video; Automated determination of resolution and views appropriate to a client's hardware and bandwidth
Cross-references: Interview 4

2. Anticipated effects in immediate markets

Intended markets:
Advertising websites
Remote shopping systems; remote interactive design and display of custom models
Chat rooms
Community and work-sharing systems; firm-wide sharing of plans and documents
Distance learning systems
Possible business models: None identified
Existing substitutes (negatively impacted): Text-based systems: chat rooms, home shopping.
Nature of gain(s) to user (as compared with existing substitutes): Improved presence, immersiveness, interactivity.
Likely limitations of technology in short-term: Detail and realism are limited by the VRML language and by the bandwidth and processing capacity available to users. Many potential users are restricted to 2-D or static images.
Additional desirable features: Insert live faces into the scene
Potential for "inventing around": High
Other future substitutes: In principle, VR rooms need not be supported by a central server. Distributed processing could be shared by the users.
Other factors on monopolization potential: None identified
Other factors on intellectual property protection: Trade secrets, high cost of development, need for two difference types of expertise: communications, VR.
National location: European firms are highly competitive
Foreign government action: None identified
Other factors on timing of innovation: Innovation is limited by computing power and bandwidth that are affordable to mass end users.

3. Anticipated effects in related markets

Complementary products: None identified
Potential for forced "tie-ins" of this product: None identified
Potential for forced "tie-ins" to this product: None identified
Upstream products (inputs to production of this product): None identified
Downstream products (uses this product as input to production): None identified
Antagonistic products: None identified

4. Knowledge spillovers
Potential spill-outs: None identified
Potential spill-ins: None identified

5. Network spillovers
Investment coordination problems: None identified
Standards problems: VRML is an object-oriented standard which demands heavy computing power. Particular VR browser plug-ins and server technology will tend to introduce additional standards. With closed proprietary standards, 3rd party vendors and competitors will have no incentive to develop complementary software, and may attempt to provide alternative standards. But with open standards, it is hard for the initial developer to recoup costs.
Hardware-software coordination: VRML attempt to make images hardware-independent. However, descriptions of scenes are in terms that may be sensitive to types of graphic accelerators available on the end-user machine.
Software-software coordination: None identified
Existing installed base (as a barrier): None identified
Future installed base (as a source of lock-in and monopolization): None identified
Other sources of premature lock-in: None identified.
Economies of scale: None identified
Direct interactions between consumers (economies of consumption): None identified
Synergies with other technologies (and economies of scope): None identified
Need for development of specialized uses: None identified
Other specialized use networks using this product: None identified
Specialized use networks to which this product belongs: None identified

6. Barriers to development or commercialization
Capital availability: None identified
Other special barriers: None identified

Interview 15: Object Tracking within Video

1. Technology description

Technology name or description: Object Tracking within Video
Technology goal: Provide facility for DV editors to identify objects in video streams, add annotation, create hyperlink connections from them, and store them as metadata; and provide facility for end-users to follow links by point-and-click.
Technology technique: Technology allows objects to be identified in one frame within a DV editor, and tracked in all other frames. The author of the video uses a computer mouse to scribble roughly on each desired object in a frame of video and the system generates full segmentation masks for that frame and for following and preceding frames until there is a scene change or the entrance of new objects. These masks label every pixel in every frame of the video as belonging to one of the regions roughly sketched out by the author at the beginning of the process Objects can then be linked to additional information so that users equipped with a pointing device can select any object on screen and follow the link (See http://www.media.mit.edu/hypersoap/ for additional information on this topic.)
Current developmental status (stage, timeline, risk): Demonstration of this technology has been developed. It was shown for the first time at the October 28-31 1998 Technical Conference and Exhibition of the Society of Motion Picture and Television Engineers (SMPTE), in Pasadena.
Selected leaders in field (experts, firms, laboratories): IBM (Hot Video), Mitsubishi Electric America (Video Shock) and Veon, (V-Active) have similar products although they are based more on a world wide web paradigm than on a TV paradigm. The Israeli military have funded some commercial research.
Related, broader technologies:
Object tracking
Video Production/Post-Production
Computer vision
Related, narrower technologies: None identified
Cross-references: interview 2; interview 13

2. Anticipated effects in immediate markets

Intended markets: This technology has applications in all areas of video production and viewing. It can be used to link television shows to product advertisements. Producers can sell product placement, eliminating the need for commercial interruptions (or turning the entire program into an advertisement). The technology can also be used to produce educational or training products. Hyperlinks would lead to other information, more detailed views, additional video streams, or interactive elements. These could be packaged as broadcast or they could be in CD-ROM or DV-ROM formats, or they could be downloadable from the Internet.
Possible business models: None identified
Existing substitutes (negatively impacted): Web, network, and cable TV as currently implemented would be significantly modified. There would be some depreciation in value of existing content, hardware, system software, and editing and programming skills.
Nature of gain(s) to user (as compared with existing substitutes): Greater flexibility of links, and wider area of kinds of information available. By integrating television with other data streams users will be able to access multiple communication media (video, TV, computer etc.) using a single technology and (eventually) a single telephone line.
Likely limitations of technology in short-term: Need a pointing and selecting device that can be produced at low enough cost to meet competitive home electronics demands. Display devices will need to be linked to enough storage capacity to save the supplementary information broadcast along with the video. More interactive applications will require network connections with adequate bandwidth and sufficient processing power at the users end. User has to be reasonably technology-savvy to be able to utilize the full potential of the technology. Limited to only one/two rooms in a house, because under the present technology, wires can’t be extended for sufficient lengths.

Limited programming currently produced to take advantage of capabilities of the technology.

Additional desirable features: Ability of end users to manipulate objects in the image so that they can be resized, removed or altered in some way. For example, the ability to change the size color or placement of subtitles for a foreign language movie.

Additional interactivity. Broadcasts of more general data streams that would allow users to manipulate what they see by changing viewing angles, removing objects or otherwise manipulating the data they receive.

Linkage of viewing devices with other household appliances to allow for the distribution of linked data for other uses. E.g., recipes linked to a cooking show could be sent directly to a display panel in the kitchen or coupons for an advertised product could be sent to a networked printer.

In DV editors, ability to automate tracking of the same object into different scenes.

Potential for "inventing around": General ideas have considerable potential for inventing around. Specific implementations may be proprietary, but the technology will need to be built on open standards and protocols.

Other future substitutes: None identified

Other factors on monopolization potential: Early entrants may have an advantage because of experience, and because they will help to shape standards.

Other factors on intellectual property protection: None identified

National location: Much of the research is being done in the U.S. but companies involved are global in operations, and will choose production locations based on cost. Some work in Israel.

Foreign government action: Some involvement by Israeli military.

Other factors on timing of innovation: None identified

3. Anticipated effects in related markets

Complementary products: Storage media, Graphics chips for set-top boxes, programming and supplementary materials to accompany it, display devices.

In the long-run the connection between video streams and supplementary information creates potential linkages of almost infinite variety. Sharing information across a household network will create complementary demands for a host of "smart" appliances as well as networking hardware and software.

Potential for forced "tie-ins" of this product: This product could be bundled with DV editors and broadcast management systems, for example. Given open standards, it would hard to impose any direct charges on viewers, so bundling with display devices.

Potential for forced "tie-ins" to this product: None identified. Unlikely to be packaged exclusively within closed proprietary systems, because the systems will be too large.

Upstream products (inputs to production of this product):

Programming

Input devices capable of generating more complex data streams–e.g., 3-D information–in real time

Receivers capable of interpreting storing and displaying information

Specialized chips for processing and rendering information streams

Downstream products (uses this product as input to production): Advertising, educational and entertainment products

Antagonistic products: Conventional non-interactive video viewing, along with other stand alone computers, and other appliances.

Various approaches to household networking are possible. The idea of smart appliances assumes a sort of self administering network which is at odds with Microsoft's vision of a windows based networking approach.

4. Knowledge spillovers

Potential spill-outs:

Computer vision research

Compression and metadata description standards

Automated object recognition software and hardware

Potential spill-ins:

Computer vision research more generally

Compression technologies and metadata description standards

Automated object recognition software and hardware

5. Network spillovers

Investment coordination problems: None identified

Standards problems: There is clearly a need for standards in metadata description. In the long-run the ability to interact with a household network will require standards for interconnection and interaction at several levels: (1) hardware for connections, (2) Data transmission protocols, and (3) communication software that manages message flows between appliances. It is unlikely that the standards themselves can be licensed or regulated by any one firm.

Hardware-software coordination:

1. There is interdependence between hardware, editing and DV management software, and content and content-stream creation and programming.

2.Most end users won't purchase the needed appliances until sufficient programming is available; but most programmers have no inventive until sufficient end-users are equipped. (This could be solved by imposing government fiats on new TV sets, for example)

Software-software coordination: None identified.

Existing installed base (as a barrier): Inferior industry standards, such as HDTV, does not possess all the promised features at present.

Long-run diffusion of smart appliances may be affected by long lifetimes of appliances and large installed base.

Cable companies, in particular, are decentralized and may have limited incentive to update their hardware.

Future installed base (as a source of lock-in and monopolization): A potential problem. Products will need to be designed with some degree of flexibility. Chips may be re-programmable, or components expected to be rapidly replaced will need to be separately packaged.

Other sources of premature lock-in: None identified.

Economies of scale: None identified.

Direct interactions between consumers (economies of consumption): None identified.

Synergies with other technologies (and economies of scope): More advanced applications will require development of more powerful processors, and inexpensive storage devices. Household networking will require development of a host of technologies needed to create self-administering plug and play networks of appliances. These may be based on "firewire" (IEEE-1349) connections, or something similar.

Need for development of specialized uses: None identified

Other specialized use networks using this product: None identified.

Specialized use networks to which this product belongs: None identified

6. Barriers to development or commercialization

Capital availability: None identified

Other special barriers: None identified

Interview 16: Device Independent Color

1. Technology description

Technology name or description: Device Independent Color for video applications

Technology goal: Numbers define digital color: they define how much red, green, and blue you want to turn on for your monitor. Or in the print world, how much cyan, magenta, yellow, and black you want to print on your printer. But to get the colors to look the same whether they are on a monitor, a printer, a digital video disk, or in a VRML world, it is necessary to specify more about what those numbers mean, in terms of the perception of color, not just in terms of the mechanics of how they make the device work.

Some areas where digital video color fidelity is especially important include:

1. Animation and special effects in film making. Before the introduction of computers into film industry, color was controlled by chemical processes, filters, etc. Now effects added to live action or entirely synthetic images are included. The effects are created on a monitor, but the monitor is not the final display device. Scanned in colors must match, and output must have the same color look as the traditional film sequences.
2. Commerce over the web. If someone is to buy clothing, furniture, or other color sensitive items over the web, the color rendition will probably need to be at least as good as in a high quality print catalog.
3. TV type broadcasts over the Web. SMPTE has a series of color standards and recommended practices for TV. As long as televisions are the only output medium, this works fine, at least in theory. But increasingly, video is displayed on computer monitors rather than on TV. Many of the display characteristics are different. This means that color management is necessary for getting color fidelity of video imagery on a computer monitor.
4. 3-D worlds are more demanding because depth perception depends on color cues. Also, VRML is typically displayed in a windowed, multi-application environment. Other formats may be displayed simultaneously. Mismatched color (especially flesh tones) will be very noticeable in this setting.

Technology technique:

1. Color conversion takes processor power, and speed is very important. Any color conversion system that can't keep up with the video being piped through is worthless.
2. Where input devices meet output devices, two color spaces are generally involved. The question is what is the best way to display color on the output device given the information from the input device. The transformation may not be easy: the input device may be able to detect colors that the output device cannot display. There are a huge number of potential input device-output device combinations.
3. Major manufacturers and software firms, working through the International Color Consortium, are converging toward solutions based on profiles. A profile is a complete description of the color space characteristics of a particular display or media device. Source images are tagged with the creation profile. Note that the development of the profile itself may be difficult. For print media, for example, different papers will create different profiles.
4. One approach is that, at creation time, an image will be converted into a well-known standard color space code. Another device that reads this image converts from the standard to its own profile. So any given device only needs to know its own profile and a standard (or standards) **--** not everyone's profile.
5. A basic problem unsolved problem is adjusting for ambient light at each end.

Current developmental status (stage, timeline, risk): Approaches to create profiles and to transform to standards under development, but not in wide use. An image format for the Web (PNG) that can make use of profiles has been developed.

There is substantial technical risk that ambient light can't be handled well.

There is a market risk that people just won't care about color, and won't be willing to pay anything for color fidelity. Anecdotal evidence here is that "most people don't even bother to tune the color on their TVs." On the other hand, people see more good color, it may raise their standards and awareness. This is similar to what has happened with word processing and typography. The appearance standards for word processor documents have risen over time.

Selected leaders in field (experts, firms, laboratories):

Industry groups: International Color Consortium http://www.color.org and its members. articles include:

Michael Has and Todd Newman. "Color Management: Current Practice and the Adoption of a New Standard."
Todd Newman. "Improved Color for the World Wide Web: A Case Study in Color Management for Distributed Digital Media."

Silicon Graphics
Don Greenberg at Cornell (color that is more real perceptually).
Imaging Sciences and Technology group http:www.imaging.org.
Apple, Xerox, HP have worked on it.
Related, broader technologies: colorimetry. Palette optimizer.
Related, narrower technologies: Device independent color for print media (such as developed by Adobe)
Cross-references: None identified.

2. Anticipated effects in immediate markets

Intended markets: All or most input and output devices would have measured profiles and color conversion capabilities. So in some sense, all TV users and all computer users are within the intended market. Users would not be buying software directly, but developments would be embodied in the products they did buy. There may be specialized markets (such as advertising) where those who create images will be especially careful to include device independent color capability in the short run.

Possible business models:

1. Consortium develops standards for device independent color based on profiles.
2. Software firms develop quick ways to "best transform" your color space to or from one of the standards. There may be different solutions for what is the "best" transform. There may be different solutions for 3-D and 2-D.

Existing substitutes (negatively impacted):

1. Bad color and applications where no attention is paid to color calibration
2. Applications where color is "tuned" in a device *dependent* manner (i.e. there are interactions between input and output adjustments)

Nature of gain(s) to user (as compared with existing substitutes):

1. Images more visually pleasing.
2. (For Web commerce): products displayed more accurately, consumers more willing to buy over Web, fewer product returns.
3. Time and cost savings (as compared with custom calibrations).

Likely limitations of technology in short-term: Difficulty in measuring profiles of equipment. Devices may get out of sync with their own profiles. processing power, time of the animation worker, and quality of software or technique.

Additional desirable features:

1. The standard color code(s) would ideally cover almost all of the range of perceptually distinguishable colors.
2. Standards would be set for handling colors that a given output device was physically incapable of producing.
3. The color code would be scalable, in the sense of allowing for different levels of precision.
4. The mapping from color code to or from the internal device signal should be innately computationally fast.
5. There should be standards for detecting ambient light, and adjusting to it.
6. Standard might be adopted for representing nonviewable (multispectral/hyperspectral) spectral information.

Potential for "inventing around": The issue here is development of a standard. There may be many ways to implement the standard. Particular implementations could involve patents or trade secrets, but non-infringing alternatives could generally be developed.
Other future substitutes: None identified
Other factors on monopolization potential: None identified
Other factors on intellectual property protection: None identified
National location: Most members of the International Color Consortium working on device independent color are US, some European and Japanese. Other organizations are CIE (Commission Internationale d' Eclairage, international), ISCC (Inter Society Color Council, US).
Foreign government action: None identified
Other factors on timing of innovation: None identified

3. Anticipated effects in related markets

Complementary products: Computers, monitors, color printers, other display devices; cameras, scanners, input devices; transmission and receiving equipment; storage media

Potential for forced "tie-ins" of this product: Profiles and standard coding conversions would have to be included with hardware products.
Potential for forced "tie-ins" to this product: None identified
Upstream products (inputs to production of this product): computing hardware and software.
Downstream products (uses this product as input to production): Advertising, video production, distribution, transmission
Antagonistic products: None identified.

4. Knowledge spillovers
Potential spill-outs: Better methods of describing and rendering color that could be used in printing, publishing, film.
Potential spill-ins: None identified.

5. Network spillovers
Investment coordination problems: None identified
Standards problems: The main issue is getting hardware devices to display color compatibly; that is, getting devices to work together.
Hardware-software coordination: The basic problem that not all colors can be transformed from one representational space to another. A color may be "out of gamut." Therefore hardware and software must agree on what is the acceptable gamut, and what happens when it is violated.
If person A is assured that person B will be able to render color well, person A will be inclined to put more effort into color fidelity, and will be more apt to undertake applications (such as Web advertising) where color is important.
Software-software coordination: None identified.
Existing installed base (as a barrier): existing output devices may not easily be adapted to new standard. Or, the standard may be adulterated to fit existing devices.
Future installed base (as a source of lock-in and monopolization): It's possible that better color standards could come along, but hardware-software set up to convert to existing standard would prevent a change-over.
Other sources of premature lock-in: None identified.
Economies of scale: None identified.
Direct interactions between consumers (economies of consumption):
Synergies with other technologies (and economies of scope): color fidelity will work with other kinds of high resolution to make e-shopping and remote DV sales systems more effective.
Need for development of specialized uses: None identified.
Other specialized use networks using this product: None identified.
Specialized use networks to which this product belongs: None identified.

6. Barriers to development or commercialization
Capital availability: None identified
Other special barriers: None identified

Interview 17 Animated Human Visual Realism

1. Technology description

Technology name or description: Animated Human Visual Realism

Technology goal: DV computer animation of human beings sufficiently realistic so that the viewer cannot distinguish it visually from movie photographs of the real thing. Human realism is the "holy grail" of animation; the human eye and brain are less sensitive to artificiality in representations of non-human than human subjects.

Technology technique: We might define a sequence of increasingly difficult sub-goals:

1. given a rough static sketch of a human body or a body part, render the static details.

2. given a rough sketch or armature showing timing of dynamic motion (such as a moving stick figure or points showing critical points on the body), render the dynamic details. (The armature is likely to come from photographs or other recordings of a moving human. Libraries of particular motions are available and will be expanded.)

3. given a general description of the motion and the body, render the detailed timing of the armature (using dynamical models of the human body's mechanics).

4. given a situation and motives (e.g., a man turns angrily and storms out of the room), model the choice and execution of motion.

The detailed rendering involves a variety of algorithms working together: e.g., generate hairs on the skin; generate micro-folds in the skin; show how skin moves over small bones and muscle during movement.

Current developmental status (stage, timeline, risk): Step 1 can be done reasonably well now, but results would not withstand close scrutiny, even by a lay-person.

Interviewee believes the step 2 goal will be accomplished within 5 years (at high expense, in a high-budget motion picture); it will require about a 20-fold increase in processor power (or reduction in processing cost).

Step 3 will accomplished a few years later.

Selected leaders in field (experts, firms, laboratories):

Terrence Masson, Industrial Light & Magic, Inc. http://www.ilmfan.com/index2.html (unofficial website of IML)
http://www.visualfx.com/digfaux.htm (Digital Fauxtography home page)
Cornell Computer Vision Group http://www.cs.cornell.edu/vision/
M. I. T. Media Lab http://www.media.mit.edu
Utah Computer Graphics and Visualization Group http://www.cs.utah.edu/~shirley/utah_graphics.html
University of Pennsylvania Center for Human Modeling and Simulation, http://www.cis.upenn.edu/~hms/badler/pap/pap.html
Stanford Robotics Laboratory, Jean-Claude Latombe's Research Group, http://robotics.stanford.edu/~latombe/projects/#E

Related, broader technologies:

3-D animation
virtual reality
medical imaging such as the visible human project, http://amanda.uams.edu/other/visman.html

Related, narrower technologies: None identified

Cross-references: Virtual reality

2. Anticipated effects in immediate markets

Intended markets: Content production for movies, broadcast TV, advertisements, as well as other newly developing video transmission methods.

Possible business models: 1. specialized knowledge and routines possessed by a single content-production agency (the usual earlier stage of commercialization for a given animation technique)

2. knowledge embedded in commercial computer programs (a later stage of commercialization). The knowledge could be developed by the software firm, or licensed from a (possibly academic) developer.

Existing substitutes (negatively impacted):

Direct photographs of human actors and stuntpersons.
Morphing and compositing from stock footage.
Less realistic forms of human animation

Nature of gain(s) to user (as compared with existing substitutes):
1. cost reductions
2. ability to simulate dangerous, expensive, or impossible actions, situations, or locations
3. increased control over voice, appearance, and/or motions of "actors"; increasingly compelling or artistic images
Likely limitations of technology in short-term: Realism is limited by processing power, time of the animation worker, and quality of software or technique. The first two limitations are relative to available dollars; the third limitation is absolute.

As the animation quality advances, audience will become increasingly knowledgeable and demanding - human realism may turn out to be a moving target.
Additional desirable features:
"Animated" or artificial voices
Increasingly high-level commands or controls on content
A long-run goal might be to develop a "synthespian" or completely artificial actor.
Potential for "inventing around": High. basic techniques are generally not patentable.
Other future substitutes: None identified
Other factors on monopolization potential: None identified
Other factors on intellectual property protection: "Keeping ahead" is likely to be the main form of protection.
National location: US shops are generally in the lead. The Computer Graphics Lab at the Swiss Federal Institute of Technology, Lausanne, http://ligwww.epfl.ch/~thalmann/, has cooperative ties with several European academic human animation groups.
Foreign government action: None identified
Other factors on timing of innovation: None identified

3. Anticipated effects in related markets
Complementary products:
Inputs to video creation: writing, directing, cameras, film or content media.
Movie houses typically sell food and drink.
Potential for forced "tie-ins" of this product: Software could be part of a broader animation package.
Potential for forced "tie-ins" to this product: None identified
Upstream products (inputs to production of this product): Computing hardware, graphics accelerators, DV storage media, software media.
Downstream products (uses this product as input to production):
Video content creation and distribution
Advertising
Antagonistic products: As an outside possibility, live actors might engage in obstructive union or political action.

4. Knowledge spillovers
Potential spill-outs: Better methods of describing types of motion could lead to more efficient algorithms for identifying and classifying objects, motion recognition, and image retrieval.
Potential spill-ins: None identified

5. Network spillovers
Investment coordination problems: None identified
Standards problems: Animation workers tend to prefer the hardware/software they are used to.
Hardware-software coordination: Software needs to work with particular graphics accelerators.
Software-software coordination: The architecture will include various rendering subroutines that must work together.
Existing installed base (as a barrier): For leading edge shops, quality concerns are likely to quickly override any sunk costs. For other shops, rapid increases in equipment quality, decreases in cost, and increases in competitive demands are likely to overcome commitments to existing capital, but in a more gradual fashion.
Future installed base (as a source of lock-in and monopolization): This is likely to become a problem only if the rate of technical improvement eventually slows down.

Other sources of premature lock-in: None identified
Economies of scale: Slight, because this is a relatively small market.
Direct interactions between consumers (economies of consumption): None identified
Synergies with other technologies (and economies of scope): None identified
Need for development of specialized uses: None identified
Other specialized use networks using this product: None identified
Specialized use networks to which this product belongs: None identified

6. Barriers to development or commercialization
Capital availability: None identified
Other special barriers: None identified

Interview 18: “Presence” Technology for Multiple Perspective DV Viewing

1. Technology description

Technology name or description: “Presence” technology for multiple perspective DV viewing of real events.
Technology goal: Give the viewer control over apparent camera point-of-view (POV)
Technology technique: Multiple continuously-running DV cameras are required at the event or site. The viewer may simply be given buttons for choosing between preselected fixed POVs, or there may be simulation of interpolated POVs as well, leading to continuous control over viewing POVs.

A primitive technology that could be used now is: broadcast continuous views from POVs over several cable channels. The viewer could use PIP and channel switching on a conventional TV to choose various perspectives.

However, in practice, ability to replay the action from alternative perspectives appears essential to marketability, so some form of searchable time-based DV database is needed.

Two technologies for interpolation demonstrated in laboratories are:
1. morphing, with closely positioned cameras;
2. full 3-D reconstruction, with widely positioned cameras. Hybrid approaches are possible but untried. Reconstruction could occur on the program origination server, but is more likely to occur at the viewer’s end.

Current developmental status (stage, timeline, risk): An existing experimental commercial application has up to 4 cameras, 3 hour latency, Internet broadcast; will be available in 1999 with only a 15 minute delay. Will be marketed over the Internet; soon, also available by DV. Only University sports events are involved at present; a separate arrangement has been entered into with each of 11 Universities. Projects are underway for football, basketball, baseball, with golf and soccer expected to follow soon. Commercial applications of interpolation are expected in 2-3 years; commercial inference of hidden items in 3-5 years. The main risk is commercial risk rather than R&D risk. Commercial surveillance systems are 1-2 years away.

Selected leaders in field (experts, firms, laboratories):
Reconstructive interpolation: Chuck Dyer, U. Wisconsin-Madison, computer vision group, http://www.cs.wisc.edu/computer-vision/
Carnegie Mellon Robotics Institute (e.g., http://www.ri.cmu.edu/projects/project_245.html)
Praja: football demo at www/actionsnaps.com
Remote controlled zoom views: Perceptual Robotics Company at http://www.perceptualrobotics.com/
surveillance systems: SVK (no cite found)

Related, broader technologies: Video surveillance; daycare surveillance
Related, narrower technologies: Time-based DV databases. Remote cameras that allow multiple users to pan and zoom.
Cross-references: None identified

2. Anticipated effects in immediate markets

Intended markets:
1. viewing sports events (available now)
2. other entertainment events
3. surveillance systems (e.g., day care monitoring for distant parents)
4. electronic commerce; travel marketing
5. telemedicine
6. display in games
7. pornography
8. satellite imaging

Possible business models:
1. The event owner retains rights and may market the product. Technology vendor operates as a value-added service, repackaging the product for various outlets (Internet, cable, DV).
2. The technology vendor purchases rights to the event and takes full responsibility for distribution. Sales could be either subscription-based, or advertiser-supported; both are being tried.

3. Conventional broadcasters purchase the technology and the event record and then take full responsibility for delivering the product.

Existing substitutes (negatively impacted): More passive ways of viewing large-scale events will gradually become outmoded.

ESPN is already putting play-by-play information on the Internet, without multiple perspective control.

Some conventional sports videos show highlights of the season.

Day-care surveillance over the Internet is already available, without POV control.

Nature of gain(s) to user (as compared with existing substitutes): Viewer can decide what viewpoint is important. Viewer can get all the available data on whatever he/she is interested in, e.g., second-guessing calls by sports officials, while skipping over or abbreviating what is not of interest. Viewer has a sense of more active participation in the event. Selection of POV makes the event more "real," more immersive.

Likely limitations of technology in short-term: Remote users must have a very large data pipe (preferably a cable modem), fast Pentium, large RAM.

Interpolation will require e.g., a 1000Mcps Pentium, available in 3-5 years.

Markets will be limited to high-spectacle events or important surveillance sites that already merit conventional coverage with multiple cameras POVs on the same event.

Additional desirable features:

1. many more camera POVs
2. simulate intermediate locations for camera POVs (interpolation; hidden items appear as a blob)
3. model or recreate hidden items
4. real time availability of actual camera POVs
5. real time availability of interpolated/recreated camera POVs
6. split screen or PIP for viewing the same action from multiple simultaneous perspectives
7. zoom view (either actual or simulated. Problem: who controls the camera? simulated zoom implies either loss of resolution or extreme high definition capture of original image)
8. increasingly immersive technology (HDTV, binocular 3-D, ...)
9. indexing of types of occurrences within the event (e.g., drives, touchdowns, hits and runs)
10. GPS metadata can be added to unrelated DV recordings, allowing after-the-fact opportunistic image merging.
11. slow motion
12. surround sound, audio viewpoints to match video.
13. holographic video input
14. multispectral input (e.g. for satellite imaging)

Potential for "inventing around": High

Other future substitutes: None identified

Other factors on monopolization potential: None identified

Other factors on intellectual property protection: Know-how and "keeping ahead" are the main forms of protection

National location: US is ahead.

France-INRIA- image reconstruction at http://www.inria.fr/Equipes/MOVI-eng.html

U.K.-University of Edinburgh - image reconstruction at http://vision.dai.ed.ac.uk/

Foreign government action: None identified

Other factors on timing of innovation: None identified

3. Anticipated effects in related markets

Complementary products:

Surveillance and security systems

Sports and entertainment events

Cameras and image capture services

Databases

All types of distribution systems: broadcasting, narrow casting, streaming, DV

Display systems

Potential for forced "tie-ins" of this product: This product could be bundled with paid remote access to sports and entertainment events. It could be offered on particular cable channels.
Potential for forced "tie-ins" to this product: None identified
Upstream products (inputs to production of this product): Hardware to run reconstruction, hardware for viewer's POV controller.
Downstream products (uses this product as input to production): Property and personal protection and security systems.
Antagonistic products: None identified

4. Knowledge spillovers
Potential spill-outs: Similar techniques could be applied to: video conferencing, distance learning, creating records of conference highlights.
Potential spill-ins: Interpolation systems could benefit from advances in morphing and 3-D modeling techniques. Some existing animation systems capture human motion from multiple perspectives and then reconstruct a 4D model (but not in real time).

5. Network spillovers
Investment coordination problems: While needed capital sums are relatively limited, several types of economic agents and activities are involved (see the discussion under "other barriers," below).
Standards problems: There is a need to standardize the financial arrangements (see discussion under "other barriers" below). The viewer's interface needs to be standardized.
Hardware-software coordination: DV and DIVX recordings of multi-POV events will be hardware dependent.
Software-software coordination: Not a serious problem.
Existing installed base (as a barrier): Not a serious problem.
Future installed base (as a source of lock-in and monopolization): Specific hardware approaches will tend to get locked in.
Other sources of premature lock-in: None identified.
Economies of scale: None identified.
Direct interactions between consumers (economies of consumption): A black market in multi-POV videos is rather likely to develop. Because outcomes are somewhat akin to a discriminating, monopoly, the effect could be to reduce profits while increasing over-all consumer surplus.
Synergies with other technologies (and economies of scope): None identified
Need for development of specialized uses: None identified
Other specialized use networks using this product: None identified
Specialized use networks to which this product belongs: None identified

6. Barriers to development or commercialization
Capital availability: Does not appear to be a particular barrier.
Other special barriers: At present, putting together a deal for an event or series of events requires very complex multilateral negotiations between, at a minimum:
1. owner of the sports events
2. owner of cameras and event records
3. owner of broadcasting rights, if different from (2) (e.g., black-out rules may be in effect)
4. vendor of multiple-perspective technology
5. vendors of distribution systems and services, if different from (4).

At present, most deals end up with unique arrangements.

Interview 19: Digital Watermarks

1. Technology description

Technology name or description: Digital watermarks.

Technology goal: To create and detect invisible watermarks on digital video signals to verify copyright protection. The mark should be invisible to the viewer, but easy for the owner to detect and verify.

Technology technique: Watermarks are digital signals superimposed upon an original image. Watermarks should have the following features:

1. Perceptual invisibility.
2. Trustworthy detection without false alarms that a watermark exists when it does not.
3. Associated key (a private number that allows casing, detection, and removal of a watermark by the owner).
4. Automated detection. Watermarks should be associated with search mechanisms so that an owner can search public domain to see if her/his creations are being used without permission.
5. Statistical invisibility, so that the watermark cannot be discovered and removed by unauthorized people.
6. Robustness. Digital images may undergo "malicious" image modifications and modifications due to compression, filtering, resizing, etc. The watermark should still be detectible after image modification. However, in cases where authenticity (and not just ownership) is important, additional "fragile" watermarks may be required.

(Note: most of above information taken from Voyatzi, Nikolaidis, and Pitas, *Digital Watermarking: An Overview*, Department of Informatics, University of Thessaloniki, 1998).

Watermarking schemes generally require three algorithms: watermark production algorithms (WPA), watermark embedding (WEA), and watermark detection (WDA).

WPAs: based on pseudo-random number generators and/or strongly chaotic systems. The watermark production must be non-invertible. For example, let K be a key (known by owner) and let G be a pseudo-random number generating function. The outcomes of the random number generator are combined with characteristics of the image to provide a modified watermark.

WEAs: a watermark is a two-dimensional signal that is superimposed onto the initial image. The characteristics of embedding should take perceptual invisibility into account.

WDAs : based on statistical hypothesis testing. WDAs may work off digital products that are not in original format: they may have been compressed or altered in other forms. WDAs may provide a yes/no answer as to whether a watermark exists, or they may provide more complex information about the probability that a particular watermark exists. Watermark detection starts with knowing the key. If the watermark exists, a detection function applied to the original image and to the watermarked image should yield the same results (but note that there are some detection algorithms that do not rely on the original image).

Current developmental status (stage, timeline, risk): A consortium of firms has just reached agreement on a standard (2/17/99). Software products are on the market, but some interviewees claim that they are not they are not immune to all potential "attacks." At the same time, there is a tremendous need for establishing ownership of DV material. In fact, some kind of watermarking is almost essential if Internet "broadcasting" of digital video entertainment and other sequences is to take off.

Selected leaders in field (experts, firms, laboratories): IBM, NEC, Phillips, Microvision, Samsung.

Related, broader technologies: Internet broadcasting, video compression.

Related, narrower technologies: Encryption/decryption; specific algorithms for each part of the watermarking process (see above).

Cross-references: None identified

2. Anticipated effects in immediate markets

Intended markets: Any digital images, still and video. But specifically, content creators whose images will or might be broadcast over the Internet.

Possible business models: Firms will develop and sells software products. Firms will advise clients on appropriate levels of watermarking for their products. Firms might do search services for copyright violations. Firms might offer verification services, whereby video distributers and users (such as a web broadcaster) could make sure their copies were legitimate. Firms could offer royalty collection services.

Existing substitutes (negatively impacted): There is not a good alternative. However, content providers can and do provide notice of copyright (which may or may not get stripped off in illegal distributions). The content providers or their agents can monitor the Web for suspicious looking broadcasts and use threats and litigation if necessary to stop unauthorized use. Ownership can be established by comparing appearance of unauthorized video with registered product, and letting judge or jury decide. Enforcement mechanisms are similar to those used to catch pirated software and music.

Nature of gain(s) to user (as compared with existing substitutes): Clear establishment of ownership, potential for owners to detect unauthorized use automatically, potential for users to verify legitimacy of copies.

Likely limitations of technology in short-term: There do not yet exist technologies that are robust to all of the kinds of distortions/modifications that are likely to happen in a broadcast setting: compression, filtering, color and brightness modifications, and geometric distortions such as cropping. In fact, watermarking goals are at odds with compression goals – one wants to embed information imperceptible to the eye, while the other wants to throw out all such information.

Additional desirable features: None identified

Potential for "inventing around": There are many approaches to the watermarking problem. It is likely that any single scheme could be modified by using slightly different algorithms. However, it is unlikely that there is a good alternative approach (other than watermarking) to the whole issue of copyright protection of digital images.

Other future substitutes: None identified

Other factors on monopolization potential: None identified

Other factors on intellectual property protection: None identified

National location: Europe has many researchers in this area, and is probably ahead of the US. The European Communities funds research in several countries, and this is a big factor in European prominence. According to one interviewee "the Americans are aggressive in marketing stuff that is not mature."

Foreign government action: see above: EC funding.

Other factors on timing of innovation: None identified

3. Anticipated effects in related markets

Complementary products: Digital signature verification (similar problem). Digital video broadcasting and content creation.

Potential for forced "tie-ins" of this product: Detection that a product has been watermarked might be built into hardware such as video players.

Potential for forced "tie-ins" to this product: None identified

Upstream products (inputs to production of this product): encryption and decryption algorithms, compression algorithms, video formatting standards.

Downstream products (uses this product as input to production): content creation and broadcast. Legal services establishing/enforcing ownership rights.

Antagonistic products: None identified

4. Knowledge spillovers

Potential spill-outs: encryption and decryption algorithms with broader uses.

Potential spill-ins: compression algorithms.

5. Network spillovers

Investment coordination problems: None identified

Standards problems: There are huge standards problems related to the relationship of compression and watermarking. Actually, we have a problem of coordination of standards. Suppose that MPEG(n) becomes the standard for digital video compression over the Internet. Furthermore suppose that watermarking algorithms are designed to be robust to MPEG(n) compression. Now suppose MPEG(n+1) comes into existence. There is no guarantee that existing video watermarks will be robust to MPEG(n+1) compression.

Hardware-software coordination: There may be hardware solutions for watermarking, which then will need to be coordinated with various compression software.

Software-software coordination: None identified
Existing installed base (as a barrier): None identified
Future installed base (as a source of lock-in and monopolization): If watermarking is to be successful, there will (probably) need to be agreement on standards and agreement on a central registry of watermarks. Once a scheme is adopted and in use, change may become difficult. Furthermore, whatever watermarking scheme is adopted may make change in other areas (like compression) more difficult.
Other sources of premature lock-in: None identified
Economies of scale: Institutions such as watermark registries have lower average cost as number of users increases.
Direct interactions between consumers (economies of consumption): informal black market content providers have an inventive to exchange methods of removing watermarks and/or make copies of watermarked materials.
Synergies with other technologies (and economies of scope): Distribution of content over Internet will be more prevalent when creators can mark their products.
Need for development of specialized uses: None identified
Other specialized use networks using this product: None identified
Specialized use networks to which this product belongs: None identified

6. Barriers to development or commercialization
Capital availability: No unusual problems identified. (Other than that more funding is always better from the point of view of researchers in the area.)
Other special barriers: None identified

Interview 20: Human Perceptual Models for Video Images

1. Technology description

Technology name or description: Human perceptual models for video images

Technology goal: Model the degree of detail and accuracy that is needed in order to satisfy human visual requirements; and then apply the model in various areas, but especially:

1. develop test equipment to
   a. tell DV content creators, broadcasters, signal distributors when their operational equipment is or is not maintaining sufficient visual fidelity; and
   b. tell equipment designers and manufacturers whether their equipment is adequate; and
2. assist technology designers, especially in areas such as video data compression, to minimize the cost or bandwidth required for maintaining a given level of visual fidelity.

A key concept is the "just perceptible difference" between two images, which constitutes a potential threshold between acceptable and unacceptable image fidelity. (If there is no perceptible difference, then the image has been successfully transformed or transmitted.)

Technology technique: There are two general approaches:

1. Vision-science-based approaches (i.e., making use of visual psychology and neurophysiology, in addition to engineering):
2. Heuristic approaches (based on engineering experience applied to small human samples):

Current developmental status (stage, timeline, risk): Test equipment is now being marketed based on both approaches. There is likely to be continued evolution but no breakthroughs. There is no clear-cut way to demonstrate the superiority of one approach over another to the satisfaction of lay-people, but scientific standards of quality may slowly trickle down from the research institutes.

At present, MPEG2 and computer animation make relatively informal assumptions about human perception.

Selected leaders in field (experts, firms, laboratories):

NASA Ames Research Center Vision Science and Technology Group,
http://vision.arc.nasa.gov/projects/projects.html
Dov Sagi, Department of Neurobiology & Brain Research, The Weizmann Institute of Science,
http://www.weizmann.ac.il/~masagi/
Christian J. van den Branden Lambrecht, Hewlett-Packard Labs Imaging Technology Group,
http://ltswww.epfl.ch/Staff/vdb.html
Tektronix

Related, broader technologies:

Signal quality test equipment
Signal compression technology
Computer animation

Related, narrower technologies: Colorimetry is an overlapping technology.

Cross-references: Video compression; human realism

2. Anticipated effects in immediate markets: Not that this technology is employed only as a component of test equipment, compression technology, and possibly other uses. Therefore effects in markets depend on the larger technologies.

Intended markets:

Image quality assessment
    Test equipment for broadcasters and service providers (lower end)
    Test equipment for DV equipment manufacturers and R&D (higher end)

Signal compression technology for transmission and data storage
(Computer animation practices may be influenced by perceptual models, but probably won't directly implement them.)

Possible business models: Test equipment:
1. the test equipment manufacturer owns the technology.
2. licensing from a (usually nonprofit) developer

DV compression:
compression schemes can be either proprietary or standardized. Licensing is possible in the case of proprietary schemes. Standardized schemes will probably be generated by industry or public consortiums and treated as public (i.e., free) goods. Because of the active interest of public regulatory bodies and the lack of existing market domination, standardized schemes are likely to replace proprietary schemes.

Existing substitutes (negatively impacted): None identified

Nature of gain(s) to user (as compared with existing substitutes): None identified

Likely limitations of technology in short-term: None identified

Additional desirable features:
1. Quality improvements. The quality of a perceptual model has three important dimensions:
    a. Supporting a minimum cost for achieving a given level of subjective fidelity (e.g., suggesting tractable algorithms for compression or signal processing);
    b. Accomplishing this goal in a provable or demonstrable manner; and
    c. Supporting this goal well in particular domains of perception (e.g., high speed wide screen movement; binocular 3-D).
2. Developing meaningful metrics for distance (and types of deviation) from an ideal such as "just barely no perceptible difference" (between two images). That is, if the signal is bad, just how bad is it, and in what ways? However, one interviewee claimed that this idea cannot be made meaningful.
3. Real time analysis.

Potential for "inventing around": High. Specific code can be patented or copyrighted, but the underlying perceptual architectures are public domain.

Other future substitutes: None identified

Other factors on monopolization potential: Test equipment: the market is small and entry costs are high. despite this, the market is presently competitive.

Other factors on intellectual property protection: The main protection consists in trade secrets and know-how, leading to brand-name reputation and loyalty. Reverse engineering is generally not possible. Even when the general outline of a proprietary perceptual model has been published, there are many specific details that need to be tweaked in practice.

National location: US, Japan, Israel

Foreign government action: None identified

Other factors on timing of innovation: None identified

3. Anticipated effects in related markets

Complementary products: Broadcasting, networking, content creation, other DV communications. Perceptual models, either explicit or implicit, are a fundamental infrastructure of the entire DV industry.

Potential for forced "tie-ins" of this product: Some efforts are being made to market proprietary compression schemes, tied in with specific software or equipment.

Potential for forced "tie-ins" to this product: None identified

Upstream products (inputs to production of this product):
Test equipment and compression hardware: equipment components

Compression software: software distribution media
Downstream products (uses this product as input to production): All phases of content production and distribution can use test equipment, but the major use is in broadcasting networks and studios.
All forms of signal recording and transmission can use compression technology.
Antagonistic products: None identified

4. Knowledge spillovers
Potential spill-outs:
Improved DV cameras, DV recorders.
Computer animation: at first, direct applications (if any) are likely to be embodied in working practices of specific animation shops. Later, it may affect the development of rendering and other utility routines.
Potential spill-ins: Vision science research

5. Network spillovers
Investment coordination problems: None identified
Standards problems: A perceptual model constitutes, or at least underlies, a de facto standard for signal characteristics. Actors at many stages in the production and distribution stream for DV content may need to agree on the particular standards. Moreover, equipment manufacturers need to meet the same standards. The problem arises continuously at all stages of analog processing; but in digital processing, arises mainly at points where the signal is converted to or from analog, or coded or decoded.

Particular networks could come to rely on particular test equipment manufacturers, leading to incompatibility of standards across the industry. That could create problems for independent content producers and manufacturers of TV monitors.

Consumers in the informal economy will exchange compressed DV media, leading to an additional demand for compression standards.
Hardware-software coordination: DV compression may involve both hardware and software.
Software-software coordination: None identified
Existing installed base (as a barrier): MPEG2 could become a barrier to new compression schemes.

All broadcasters have particular video test equipment already installed. The digital transition will lead to widespread reconsideration, however.
Future installed base (as a source of lock-in and monopolization): Studios and studio engineers will get accustomed to specific equipment, making them unwilling to change. The effort involved in shifting test equipment could be high in proportion to any expected increases in signal fidelity.

Compression schemes fixed in hardware are hard to change. (If implemented in software, there is a high run-time computational burden.)
Other sources of premature lock-in: None identified
Economies of scale: Test equipment: these are not mass markets; expected scale is small.
Compression technology: widespread use will lead to low prices.
Direct interactions between consumers (economies of consumption): None identified
Synergies with other technologies (and economies of scope): Improved perceptual models may lead not only to improved compression schemes, but more generally to less expensive ways to achieve immersiveness.
Need for development of specialized uses: None identified
Other specialized use networks using this product: None identified
Specialized use networks to which this product belongs: None identified

6. Barriers to development or commercialization

Capital availability: None identified

Other special barriers: For test equipment: small scale of the potential market.

In general, perceptual models tend to have public goods aspects that make them hard to exploit commercially.

Interview 21: Broadcast Digital TV

1. Technology description

Technology name or description: Digital television broadcast.

Technology goal: To send digital terrestrial (not cable or satellite) broadcast signal. To increase the potential quality of video and audio received by consumers. But note that digital broadcast is not the same as HDTV. The digital broadcasts are not necessarily high definition.

Technology technique: (from FCC Website www.fcc.gov, "Frequently Asked Questions about Digital Television and Digital Television Facilities.")

The information used to make a TV picture and sound is transmitted as "data bits." This allows a digital broadcaster to carry more information than is currently possible with analog broadcast technology. This allows for the transmission of pictures with higher resolution for dramatically better picture and sound quality than is currently available. It is also possible to broadcast several "standard definition" TV programs at once. "Standard definition" digital TV pictures would be similar in clarity and detail to the best TV pictures being received and displayed today using the current (analog NTSC) broadcast system and TV receivers. The DTV technology can also be used to transmit large amounts of other data that can be accessed by computers and TV sets.

DTV gives broadcasters three new capabilities:

1. high-definition;
2. multicasting (in this context, defined as broadcasting several programs simultaneously within the allotted bandwidth.);
3. enhanced service provision (such as interactivity and broadcast of supplementary data**).**

Current developmental status (stage, timeline, risk): Timeline: (from website www.pbs.org)

April, 1997: FCC gives broadcasters $70 billion worth of spectrum to broadcast digital alongside analog until 2006. FCC also mandates that in 2006 all broadcasts must be fully digital.

February, 1999: **-** The National Association of Broadcasters announces that over 50 television stations are delivering digital signals. The signals reach nearly 40 percent of all U.S. households., the stations are now serving a wide cross-section of the country -- from the largest market (New York) to the 90th market (Jackson, MS).

November, 1999: Broadcasters must have digital stations in top 30 U.S. markets (50% of viewers).

May 2002: All commercial stations must have started digital broadcasts.

2006: Broadcasters must relinquish extra broadcast spectrum and broadcast only digital.

Studio conversion:

Many TV stations are in the process of converting studios to digital. Digital studios have a lot of advantages (like capability for special effects) even if broadcast is still analog. Studio personnel will become very familiar with digital equipment even before their stations start digital broadcasts.

Transmission facilities:

New DTV transmitters and antennas must be installed and sometimes new towers must be constructed before the stations can be on the air with their digital television signals. Concerns have been transmitted to FCC that local regulatory processes will keep some stations from constructing towers in time to meet FCC mandates.

Selected leaders in field (experts, firms, laboratories): PBS, working with Harris Corporation, has been prominent in demonstrating HDTV and DTV capabilities (PBS and Harris have a broadcast station in a truck that is touring the nation through June, 1999) . As of the end of 1998, seven public broadcasting stations were providing digital signals. Public broadcasters have been instrumental in communicating to manufacturers what capabilities they want, and in lobbying manufacturers to provide equipment that fits their needs (from *Current*, August 4, 1997).

Equipment Manufacturers: At minimum, a station needs a new antenna and transmitter to broadcast DTV. Many stations will also build new towers. In general, all of the studio equipment will be digitalized as well.

Antennas: Dielectric, Harris

Transmitters: Harris, Comark, Acrodyne, Larkan

Towers: Kline, Stainless, International Towers

Studio equipment (e.g. cameras, recorders, non-linear editors, databases, routers): many vendors

Related, broader technologies: Compression (MPEG-2) is part of the standard for DTV transmission. Content-creation technologies (such as non-linear editing and special effects) will be used to create digital programs. Transmitters are used in many fields other than TV. Cameras, recorders, and video display units are used in all forms of TV.

Related, narrower technologies:

Specific program-control technologies, such as mechanisms for switching seamlessly from multiple standard definition broadcasts to one high definition broadcast (see business models section below for discussion of multiple broadcasts.) Technologies for adding station-specific material to network feed (without doing full decompression and compression).

Cross-references: Interviews 5, 11, 16, 18

2. Anticipated effects in immediate markets

Intended markets: It is intended that DTV will be the sole form of terrestrial broadcast in US by 2006. The potential market is every US household.

Possible business models: There is much discussion about the extent to which high-definition television will actually be broadcast. Stations also have the capability of using their bandwidth for multiple lower-definition (but of course still digital) broadcasts. TV stations will need to decide how to use their channels based on characteristics of their audience.

One possible model is that many lower-definition broadcasts will be televised during the day, with prime-time features broadcast in high-definition. This model is especially appropriate for public TV, where daytime broadcasts are typically comprised of educational and children's programs, while nighttime broadcasts are comprised of nature, geography, art, and travel programs that could really benefit from high-definition.

Stations will have the capability to broadcast programs enhanced with other data. (see discussion of PBS interactive biography of Frank Lloyd Wright, http://www.current.org/dtv/dtv822i.html.) But one interviewee believes that marketing studies don't show much demand for these additional capabilities.

Existing substitutes (negatively impacted): (includes potential future substitutes)

For a period of time, analog TV and DTV will co-exist. Analog broadcast (and its associated equipment) is a substitute that is negatively impacted.

Broadcasters, cable, and satellite providers are all vying for the same audience. Satellite providers are already providing a digital signal of standard definition and in standard format. It will be fairly easy for them to convert to HDTV format. For the most part, cable companies still need to make the change to digital. DTV may hurt cable in urban areas (within range of transmitters), because the images produced by the digital broadcast signals will probably be much more clear (without ghosts and static) even for standard-definition broadcasts. There is some heated discussion between cable companies and broadcasters over the "must carry" local TV signals. Broadcasters would like to be compensated for these. Cable companies will probably end up carrying the digital bit streams of broadcasters exactly as they are broadcast.

Less directly, DTV may compete with the computer industry, or at least with some planned directions that the computer industry might take. Aside from the general competition of computer related equipment for consumer dollars, there is competition for consumers' leisure hours. Hours spent in front of the TV are not spent on the Internet. The competition becomes more direct as computers starts to be used to receive entertainment programs. According to one interviewee, "the computer industry is trying to kill broadcasting."

But to date, the bandwidth available in a TV broadcast (20 Mbps) is vastly superior to the bandwidth that people get using modems (20 Kbps).

Nature of gain(s) to user (as compared with existing substitutes):

Clearer picture, up to HDTV

Wider picture aspect ratio

More channels over the air (multicasting)

Broadcasting of auxiliary data and local interactivity

Reduction in public bandwidth needed

Likely limitations of technology in short-term: In short run, few homes will have receivers that can make full use of HDTV signals. Interactivity will also lag. HDTV content and hours of broadcast will continue to be limited in the near future.

Additional desirable features:

more educational and other programs appealing to small segments of the audience (using additional channels available)

Non-local interactivity using a back-channel

Potential for "inventing around":

For the technology viewed as a whole, none. Broadcast DTV constitutes a standard.

For component equipment protected by patents, inventing around is nearly always possible, which places limits on monopolization potential.

Other future substitutes: Cable, satellite, and Internet, as discussed above.

Other factors on monopolization potential:

Broadcast DTV includes a large number of component technologies and services. Continued anti-trust action may be needed to prevent monopolization of national networks and of stations within a given market. Equipment suppliers for content providers, studios, network hardware, and transmitters have generally been competitive in the past, but monopolization is possible for some particular types of specialized equipment because the market can absorb only a limited number of units. Antennas and appliances for the end user are likely to be competitive.

Other factors on intellectual property protection: none identified.

National location: Standards for advanced television developed in US (by Advanced Television Systems Committee) and adopted by FCC. Canada, S. Korea, Taiwan, and Argentina have adopted the same standards.

Foreign government action: Japan developed an earlier standard for analog high definition TV.

Other factors on timing of innovation:

Broadcast DTV is a large industry that is following an adoption/diffusion curve.

3. Anticipated effects in related markets

Complementary products: Video content.

Potential for forced "tie-ins" of this product: none identified

Potential for forced "tie-ins" to this product: To take full advantage of HDTV, consumers will need new TV sets. At minimum, consumers will need set-top converters to receive any signal at all once broadcasters terminate analog signals.

Upstream products (inputs to production of this product): equipment suppliers and personnel will have to adapt to the changeover.

Downstream products (uses this product as input to production): advertising will have to adopt DTV formats.

Antagonistic products: conventional analog TV, possibly satellite and cable broadcast.

4. Knowledge spillovers

Potential spill-outs:

New techniques for video storage and retrieval. These are useful in many areas of DV.

Development of standards for studio equipment and editors.

Development of standards for interchange of content with cinema.

Potential spill-ins: Compression techniques, techniques for storage and retrieval, NL editors, high speed/high capacity digital switching.

5. Network spillovers

Investment coordination problems: Households invest in HDTV receivers while broadcasters invest in HDTV transmitters and content. Each side waits for developments on the other side.

Standards problems: Many standards have already been developed. May need additional standards for network feed so that stations can add information without going through full decompression-compression. Internal standards for studio and network equipment are needed.

Hardware-software coordination: need to get studio and broadcast equipment to work together.

Software-software coordination: none identified.

Existing installed base (as a barrier): conversion to digital TV makes analog transmission facilities and TVs obsolete.

Future installed base (as a source of lockin and monopolization): once a conversion has been made, it is unlikely that alternative technologies that might require new transmission facilities or new consumer TV sets could get a foothold in the market.

Other sources of premature lockin: None identified.

Economies of scale: These have already been realized for standard-definition TV. Fixed costs can be spread over more consumers.

Direct interactions between consumers (economies of consumption): Terrestrial TV broadcasts do not have "feedback" channels. It is, however, possible that consumers will interact via some other means (such as computer) to broadcast programs.

Synergies with other technologies (and economies of scope): The DTV transition will be a step towards convergence of TV with the Internet and computing.

Need for development of specialized uses: none identified.

Other specialized use networks using this product: none identified.

Specialized use networks to which this product belongs: none identified.

6. Barriers to development or commercialization

Capital availability: Small TV stations and public TV stations may have some difficulties paying for studio and transmitter conversions. Cost estimates for public TV stations range from $2 million for a station that could do little more than transmit national programs to $6 million for a facility that could produce its own programs. The total costs of conversion for public TV alone will be around $1.8 billion, the equivalent of the entire income for public TV plus public radio for one year. (source www.current.org).

Other special barriers: None identified.

9. SUMMARY OF POTENTIAL IMPACT PATHWAYS

Purpose and overview

Theory and data presented in previous chapters show an extremely large number of possible pathways through which the Advanced Technology Program digital video focus area could affect the US economy. Depending on particular aggregation choices, there are hundreds or even thousands of DV-related technologies, the majority of which would presumably be eligible for ATP funding. Each DV technology could in principle have spillovers affecting tens or hundreds of other technologies, and the spillovers are of five or more kinds (depending again on aggregation). In practice, based on a sample of technologies examined in detail, typically for each technology upwards of 10 spillovers can be identified as being of likely economic significance. Each spillover in turn can affect patterns of investment, production, consumption, and trade in multiple sectors of the economy. At the very least, any very detailed analysis would have to deal with thousands of specific impact pathways.

This multiplicity of possibilities raises problems of aggregation, presentation, and, more fundamentally, purpose. A catalog of impact pathways might be used for many different and distinguishable purposes, including:

- guiding a prospective impact study that predicted some kind of average impact of future ATP R&D investments (which have not yet been determined), with the average taken (for example) over all of the possible portfolios of DV R&D that ATP might reasonably plan to assist;
- guiding a retrospective impact study that followed a small number of digital video R&D investments after they were made by ATP;
- assisting ATP personnel in their DV funding decisions, but in a more informal way; or
- simply giving the reader a general sense of the kinds of impact pathways that are likely to follow from ATP interventions.

These examples of purposes have been arranged in descending order, from most demanding to least demanding.

The most demanding purpose would be a prospective impact study that actually examined all of the possible future impact pathways (and perhaps gave them some kind of probability weighting). Such a study is just not practical. Merely listing all of the significant pathways is difficult, though doable; but actually forming meaningful impact predictions for each and every pathway is not an affordable undertaking.

A much more reasonable kind of prospective impact study would be one based on a sample of pathways. In this case, there would be no need to actually list the universe of significant pathways; instead, one would select an affordable sample of technologies from the technology map of Chapter 6, and then analyze the significant pathways for that sample alone (and then predict the future impacts using models that still need to be determined). Indeed, Chapter 8 approximates such a sample of pathways.[18]

A retrospective impact study would be simpler yet. The problem of defining a random sample would not arise; instead we would simply analyze the potential impact pathways of technology R&D efforts that were actually selected by ATP, using interviews and other techniques like those developed in this report (and then monitor the actual impact outcomes, using methods not yet determined). That can't be done, however, until after ATP has actually selected the DV R&D it will support.

In this chapter, therefore, we do not attempt to present an exhaustive and explicit catalog of significant pathways. Instead we address the last two purposes, seeking to assist ATP funders as well as general readers. To that end, we will aggregate our results in terms we hope will give a general sense of the potential impacts of DV research and innovation. We will use a high level of aggregation, and within that framework provide some more disaggregated detail. Readers interested in completely disaggregated (if selective) results are referred to Chapter 8.

Aggregation scheme

Our discussion will be organized around spillovers between the four very general groupings of technologies that were used in previous chapters, plus one additional grouping for the rest of the economy:

- DV Content Creation, Capture, and Display
- DV Data Storage, Access, and Retrieval
- Transmission and Management of DV Data Streams and Intellectual Property
- End uses of DV Data Streams
- The rest of the economy.

Conceptually, we have a 5x5 grid of pairwise interactions, with possible spillovers from and to each of the five technology groupings. (Spillovers are possible within the same grouping as well as across groupings.) We will consider three kinds of spillovers:

- knowledge spillovers
- network spillovers
- market spillovers

Two additional kinds of spillovers (fiscal and material) will not be discussed; as pointed out in Chapter 7, the first kind does not vary much qualitatively across types of innovation, while the second kind appears to be relatively rare. Also, we will not discuss the points of contact that each spillover makes with the macro-economy; in empirical applications, those points of contact can be inferred from the arguments made in Chapters 3 through 5. Finally, we do not discuss effects of and on market

[18] However, our sample of technologies was intended to be broadly representative rather than random.

structures; those effects were discussed in Chapter 7, and generally have to do with single technologies rather with the pairs of technologies being considered here.

Spillovers from DV Content Creation, Capture, and Display

Within DV Content Creation, Capture, and Display

Knowledge spillovers may occur between applications within this technology grouping. For example, human perceptual models can be used for optimizing trade-offs in immersiveness at a given bandwidth (e.g., between color, motion, spatial resolution) and for designing animation methods and special effects.

To DV Data Storage, Access, and Retrieval

Network spillovers. The demand for storage, cataloging, and search and retrieval services for DV data is interdependent with creation of DV data. More data will enhance value of these services.

To Transmission and Management of DV Data Streams and Intellectual Property

Network spillovers. Demand for efficient transmission and Intellectual Property Protection is interdependent with the supply of content being created.

Knowledge spillovers. Plug-in architectures for editing systems like Photoshop could help suggest plug-in architectures for systems that create metadata. New ways of encoding and representing data streams for display (e.g. color standards) will lead to changes in transmission and control technologies.

To End uses of DV Data Streams

Network spillovers. Technologies for use of DV will increase in value as a result of advances in content creation.

Knowledge spillovers. Virtual reality modeling methods used in animation or content creation could also be useful in collaborative work systems. Knowledge gained about successful user interfaces for authoring systems could be helpful in designing user interfaces in automated consumer services.

To the rest of the economy

Market spillovers. Creators of content—actors, producers, etc. will capture some of the "consumer surplus" that results from falling content creation costs. Business training and communication will benefit from reduced costs and increased quality.

Spillovers from DV Data Storage, Access, and Retrieval

To DV Content Creation, Capture, and Display

Network spillovers. Better access to DV content will increase the value of content creation.

Market spillovers. Content producers are likely to be customers of storage/retrieval equipment and will capture some of the resulting benefits

Within DV Data Storage, Access, and Retrieval

Knowledge spillovers within this technology grouping are likely to revolve around solutions to fundamental problems. For example, improvements in object and pattern recognition methods will underlie improvements in automated cataloging, indexing, searching, and summarizing.

To Transmission and Management of DV Data Streams and Intellectual Property

Network spillovers. The value of transmission and intellectual property protection will be enhanced by better access to DV data.

Knowledge spillovers. Ways of categorizing and searching data could involve compression and summarization of information in ways that convey benefits for design of more efficient transmission.

Market spillovers. IP protection will benefit from advances in monitoring and categorizing content to check for violations.

To End uses of DV Data Streams

Network spillovers. The value of applications for end use will be enhanced by greater ease of access to DV data.

To the rest of the economy

Market spillovers. Consumers will capture market spillovers from falling costs of search and retrieval.

Knowledge spillovers. Object and pattern recognition methods developed for data access in a visual context could have non-visual applications, for example in analyzing repetitive patterns in time-series data.

Spillovers from Transmission and Management of DV Data Streams and Intellectual Property

To DV Content Creation, Capture, and Display

Network spillovers. The value of techniques for content creation will increase with better transmission and IP protection.

Knowledge spillovers. Techniques for compression may suggest new approaches to special effects and virtual reality rendering, especially if they are based on human perceptual models. Compression is useful in non-linear editing systems because of the high costs of storing large DV datasets.

To DV Data Storage, Access, and Retrieval

Network spillovers. The value of techniques for searching, etc. will be enhanced by improved access and IP protection.

Knowledge spillovers. Solutions to compression, transmission and identification of IP rights, may benefit techniques for storage and access. DV transmission compression methods would be helpful to storage methods, and might also suggest algorithms for analyzing content of images for access and retrieval.

Within Transmission and Management of DV Data Streams and Intellectual Property

Knowledge spillovers within this technology grouping could occur, for example, if compression techniques suggested watermarking techniques.

To End uses of DV Data Streams

Network spillovers. Value of technologies for end uses will be enhanced by improved transmission.

To the rest of the economy

Market spillovers. In at least a relative sense, there will be negative effects on telecommunications and network suppliers to the extent that compression reduces the demand for bandwidth.

Network spillovers. Negative market spillovers will be offset by network externalities that raise demand for services.

Spillovers from End uses of DV Data Streams

To DV Content Creation, Capture, and Display

Network spillovers. Content creators will benefit from development of end use techniques.

Knowledge spillovers. Interactive distance learning systems will include authoring and rendering techniques that could be useful in content creation.

To DV Data Storage, Access, and Retrieval

Network spillovers. End use techniques will enhance the value of storage and access.

To Transmission and Management of DV Data Streams and Intellectual Property

Network spillovers. End use techniques will enhance the value of transmission and IP control.

Within End uses of DV Data Streams

Network spillovers. Within this technology grouping, there may be coordination benefits across different types of products. For example, the same equipment and data used by a DV inventory control system, could support a security system.

To the rest of the economy

Market spillovers. Consumers will capture some of the benefits associated with new uses and falling costs.

Spillovers from other parts of the economy
(especially, computers, processing equipment, telecommunications equipment, and services)

To all aspect of DV technology

Market spillovers. These sectors will be among the suppliers to every type of DV application, and will produce market spillovers as costs fall.

To the rest of the economy

(Not relevant to the study.)

10. CONCLUSIONS

Approach

This report has analyzed the possible pathways through which the ATP Digital Video Focus Area could affect the US economy, and as such provides a model that could be applied to the analyses of impacts of other kinds of technology. We have employed three important theoretical ideas:

1. Following Lancaster [1971] and based on Burress *et al* [1998], we have disaggregated DV technologies in terms of the functions or uses they serve, in the context of markets for particular bundles of functional characteristics.

2. Following Jaffe [1996], we have viewed impact pathways as concatenations of "spillovers" of technology innovation, meaning unintended side effects or consequences that go beyond the profits received by the innovators. We have refined the "spillover" concept to include five general classes:

A *knowledge spillover* is any knowledge received that is neither directly paid for nor received as part of an exchange transaction.

Fiscal spillover refers to taxes or other monetary payments that are not part of any exchange transaction.

Material spillover refers to benefits or burdens, other than knowledge or dollars, that are received outside of any exchange transaction.

Market spillover refers to producers or consumers surplus; i.e., the value received by a party in an exchange transaction, over and above the barest minimum needed to motivate the exchange.

Network spillover refers to the additional benefit or burden that happens when additional agents and/or additional objects of exchange are added to an exchange transaction.

3. We have embedded our analysis in a computable general equilibrium (CGE) model of the US economy. The CGE model serves as an accounting framework to distinguish what is, and what is not, a distinct pathway of impact.

Summary of findings

There are an extremely large number of possible economic impacts of DV technologies

The most important implication of this report is not that any one method of analyzing the channels of technology impact is better than another. Instead, it is that *any* sufficiently systematic approach is likely to turn up an extremely large number of possible impact pathways.

Partly, this is because any important field of technology is innately complicated; hence it can potentially be disaggregated into a large number of sub-technologies. In particular, we are able to distinguish more than 500 individual digital video technologies (depending on level of aggregation chosen).

And partly, this is because there are a large number of possible connections or "spillovers" between subtechnologies, and also between subtechnologies and points of contact with the larger economy. Our theoretical analysis shows that the potential number of distinguishable pathways is extremely large. For example, if we assume the following (not unreasonable) levels of disaggregation:

200 detailed technologies
only 1 innovation per technology (e.g., its introduction)
5 classes of spillovers
8 types of contact point that spillovers can make with the CGE model
knowledge spillovers between innovations not followed for more than 1 step
network spillovers between innovations not followed for more than 2 steps,

then we would have tens of millions of distinguishable pathways. Moreover, our empirical analysis shows that, in the case of digital video, a rather large number of pathways actually are of potential economic significance.

Consequently, to carry out any meaningful discussion it is necessary to group the technologies at a high level of aggregation. At the most aggregated level, we distinguished four groupings of DV technologies. The groupings are defined in terms of the general function or end use, and consist in:

- DV Content Creation, Capture, and Display
- DV Data Storage, Access, and Retrieval
- Transmission and Management of DV Data Streams and Intellectual Property
- End uses of DV Data Streams

Large numbers of knowledge and network spillovers are potentially significant

Empirically, potential knowledge spillovers of some importance can occur in either direction across almost all pairs of these aggregate technology groupings. For example, advances in visual pattern recognition methods could either grow out of, or have potential applications to, content creation (e.g., computer animation methods), DV access (e.g., locating images by type), DV transmission (e.g., designing compression strategies that depend on content), or end use (e.g., human-computer interface models). Moreover, there are potential knowledge spillovers to technologies entirely outside the DV area (e.g., applications of pattern recognition to complex data analysis).

Network spillovers are likely to occur across any subset of these four groupings. At the highest level, there is a fundamental and positive network spillover in which the entire complex of DV technologies complement each other. For example, if any element in the chain from content creation through storage and transmission to end use becomes less costly, then the market for end uses is likely to expand; an expanded market is likely to lead in turn to more varieties of content being produced; (if markets work as they should) more variety in turn means more choice and increased value received by the consumer. Moreover, there are network spillovers in relation to technologies entirely outside the DV area. For example, falling prices in microelectronics or computers leads to falling prices in DV, which may trigger renewed R&D efforts in DV. Improvements in DV, in turn, could lead to improved design and production methods in computers and microelectronics.

Knowledge and network spillovers could also be significant among technologies within each of these four groupings. For example, the components of a transmission system work together as a network. Also, there could be knowledge spillovers between transmission protocols and methods for implementing “aware” networks that adapt themselves to equipment conditions and availability and network usage.

Market, fiscal, and material spillovers are simpler to analyze

Market and fiscal spillovers are much less interesting than network and knowledge spillovers, because both market and fiscal spillovers are innate and ubiquitous. Every successful technology innovation will be commercialized through market transactions which produce added value for both buyer and seller -- a market spillover. Market transactions also lead to taxable events -- a fiscal spillover.

What is most interesting about material spillovers is that relatively few of them have been identified. The production of DV-related hardware and of electricity to power DV applications will place some burden of pollution on the environment. The use of DV equipment in safety-related functions may have some positive impacts on third parties who were not part of the chain of commercial transactions.

Spillovers and market structures may act as barriers to R&D

The *distribution* of market and fiscal spillovers between buyers, sellers, and government is likely to be sensitive to the market structure, and especially sensitive to the degree of competition on the supply side. We find that many DV technologies are likely to be competitive in the next 5-7 years because basic information tends to be common knowledge and there is much opportunity for inventing around patents and trade secrets. That suggests that in some cases there could be underinvestment in R&D because of an anticipated inability to recapture sufficient rents on intellectual property rights.

More generally, the potential pervasiveness of all classes of spillovers suggests that underinvestment in DV-related R&D could be a widespread problem. Given the intensity of existing DV R&D efforts, this might seem counterintuitive -- however, if the expected social returns to DV R&D are sufficiently high, then it might be better if the overall level of DV R&D were even higher than it already is. Moreover, even if the general level of R&D is high enough, the level of spillovers could be especially high in particular niches, leading to uneven investment in R&D. In any case, these are empirical questions for future research. The purpose of the present report is to raise these questions, not answer them.

If there is underinvestment in R&D, then ATP interventions could have real impacts on the timing or national location of DV innovations. This will be a major topic for future research.

In the longer run, if the pace of technical change slows down in some of the particular technologies, then market leaders with significant market power are likely to emerge because of forces such as returns to scale (e.g., the innately low marginal cost of duplicating software) and the user's installed base of equipment and skills. In addition, as DV becomes increasingly synonymous with the whole of the entertainment industry plus the communications industry, the possibly innate tendencies of those two industries toward monopoly could come into play (if it is not restrained through anti-trust action). Major industry concentrations could create monopsony buying situations for much of the DV-related technology.

Accuracy

It is in the nature of things that this report provides an incomplete roadmap. It is likely that many technologies and impact pathways believed to be of potential significance will turn out in the event to be of no account. It is a practical certainty that other technologies and pathways will turn up whose importance we had not anticipated. The empirical descriptions of pathways included in this report reflect our efforts, as well as efforts by digital video experts, to see into the future "through a glass, darkly." It is certain that much has been missed.

On the other hand, we believe that our analytic structure is relatively complete. When new pathways show up in the future, they will generally correspond to the particular patterns of spillovers, spillover classes, and points of contact with the larger economy, just as they have been classified in this report. In that sense, no new pathway will be a complete surprise.

Moreover, the analytic structure is a guide that suggests where we should look to locate new pathways of impact. It suggest what kinds of questions to ask when we track the development of digital video technology over time. And it suggests which economic actors and agents we should address those queries to.

This is not to say that any part of our structure is necessarily very surprising. What is perhaps surprising is the vast number of possibilities that can be seen to exist, once they have been systematically cataloged.

Applications and additional research

And of course this does not imply that the analytic structure itself cannot be changed or be improved. If this structure gets used at all, then there is no doubt that it will be changed and adapted by its users.

Among the likely users are the authors of this report. In planned future research, we intend to apply these pathways in a systematic effort to track the effects of ATP's Digital Video program on the US economy.

APPENDIX 1: A Formal CGE Model

1. Equations of the model

1.0. Some notation and modeling conventions

All variables in the model are functions of time, but we will usually suppress the functional dependence on time because the model is quasi-static and time is usually not relevant.

δ prefix on a variable in the CGE model: denotes a change in that variable that is an initial effect of an ATP intervention (i.e., an effect that happens outside the CGE model). δ is used to flag the points where ATP interventions can make contact with the CGE model.

We assume that the model will be solved twice, once to describe the actual world with ATP intervention, and once to describe a counterfactual world in which ATP does not exist.

δ refers to *differences* between the two worlds. We have for example,

$$\delta K_T = K_T(\text{actual world}) - K_T(\text{counterfactual world}),$$

where K_T is a vector of dummies for technologies available and in use at time t.

Ordinarily however we will focus on the behavioral equations, which are the same in both worlds, and suppress the indicator for actual or counterfactual world.

Δ prefix on a CGE variable: indicates change in the solution to the CGE model that results from all of the 'δ' changes. That is, it represents an economic impact. For example,

$$\Delta x = x(\text{actual world}) - x(\text{counterfactual world}) = \text{total effect of ATP on } x$$

where x is a vector of outputs in the economy. If the CGE model is approximately linear and δK_T is the only effect ATP has on the CGE model, then we would have an equation such as

$$\Delta x = \Gamma \delta K_T$$

where $\Gamma(t)$ is a constant multiplier matrix that could be determined by solving the CGE model P+1 times and taking P first-order differences in x (where P=dimension(K_T)). However, if ATP has sufficiently large effects on the economy, then non-linearities are certain to be important. In that case given any K_T we would have to solve the CGE model separately for $x(.;K_T+\delta K_T)$ and calculate

$$\Delta x = x(.;K_T+\delta K_T) - x(.;K_T)$$

* suffix on a CGE variable: denotes that it is exogenous or predetermined.

ℓ : denotes a vector of 1's. The dimension of ℓ is determined by the context.

1.1. Kinds of goods

The kinds of flows in the CGE model are (number of sectors, description):

- L ordinary goods and services
- M capital services, including labor and leisure time (treated as returns to human capital), excluding technology knowledge
- M capital additions
- N technology knowledge services
- N technology knowledge additions.

The kinds of capital stocks are:

- M ordinary capital stocks, including physical capital and human capital. To simplify exposition we assume that inventory stocks can be aggregated with other forms of capital
- N technology knowledge stocks

1.2. A quasi-static model of investment

1.2.1. Investments

Since we are focusing on R&D, and R&D is an investment, we will need to include separate accounts for investment stocks and flows and for knowledge capital stocks and flows in our model. Also, a key issue is whether ATP investments affect the total R&D budget or merely substitute for other R&D. We will leave that issue as an exogenous bridge model: δn. (Note that some of these issues could be endogenized in a more general, i.e., dynamic, intertemporal CGE model.)

K = K*[(M+N)×1] = predetermined human and physical capital and inventory and technology knowledge capital. The last N elements of K are knowledge capital, which requires special treatment. We describe it as follows.

$K_T = K_T$* [N×1] = a vector of dummies for technologies available for use at time t (whether or not they are actually used). We then express K = $[K_0', K_T']'$, where K_0 is human capital, physical capital, and inventory stock.

n = n*[(M+N)×1] = vector of gross investment (additions to K). We will assume an exogenous investment vector n(t) =n*(t) in each time period.

j = j*[(L+M+N)×1] = vector of commodity demands needed to implement gross investment n. We define

$j = bn$, where

$b = b^*[(L+M+N)\times(M+N)]$ = capital requirements matrix. b is defined to include R&D investments needed to create new knowledge, as well as ordinary investments.

Investments j and n, ordinary capital K_0, and knowledge K_T can be affected by ATP actions; let δj, δn, δK_0 and δK_T be the resulting changes. Note that $\delta j = b\delta n$, so δj is not an independent contact point between ATP intervention and the CGE model.

Since n consists in additions to K_T, it follows that the last N elements of n (denoted last(N, n), i.e., the changes in K_T) are also (1,0) dummies.

Note also that last(N, δn) and δK_T can take on values (-1, 0, 1).

1.2.2. Quasi-dynamics

We will need to specify how investment in one period affects capital stocks in the next period, so that we will have accounting consistency across time for the temporary equilibria. Let

$\mu = \mu^*[(M+N)\times(M+N)]$ = exogenous depreciation rate matrix, presumably diagonal. Knowledge does not depreciate, so μ is zero in the last N diagonal elements.

The capital growth identity is:

(1) $$K(t+1) = (I-\mu)K(t) + n(t)$$

where t is time. Hence $K(t) = K^*(t)$ - i.e., capital is predetermined. Note also that the last N elements of δn will obey

$$\text{last}(N, \delta n(t-1)) = \delta K_T(t)$$

i.e., the change in knowledge investment due to ATP one period appears in the next period as the change in knowledge stock due to ATP.

1.3. Production

As noted above, there are three kinds of output (commodities, capital investment, knowledge investment). There are two kinds of production (output, capital services).

1.3.1 Output

$x[(L+M+N)\times 1]$ = output, including L commodities and M physical and human capital additions and N technology stock additions, but excluding capital services. It will be helpful to define:

$\psi = \psi^*$ [(L+M+N)×1] = dummy vector for kinds of goods and services available in the market at time t (again excluding capital services, but including technology stock additions). Then as usual, $\delta\psi$ = changes in goods due to ATP. Note however that ψ is partly a function of K_t; but we will leave this dependency implicit. (Introducing ψ is simply a notational convenience) Note that we have:

$$x'(\ell - \psi) = 0.$$

1.3.2. The production of output

Output is produced with a CRTS technology. However, in the sectors that produce technology knowledge, output takes on only the discrete values 0 or 1 and the CRTS restriction has no effect on the model. Apart from this restriction, production of investments in physical and knowledge capital have the same functional forms as commodity production. We will specify production in terms of:

$u = u(x, P, \Omega; K_T, \psi) = [u_x', u_k']'$ = cost-minimizing conditional input demands by each output sector, given prices P and Ω, where

u_x [(L+M+N)×(L+M+N)] = matrix of intermediate input demands, excluding labor and capital and knowledge services; and

u_k [M×(L+M+N)] = matrix of input demands for (M kinds of) labor and capital services. We leave the input demand for technology knowledge services implicit.

(We will have to chose a definite functional form for u to operationalize the CGE model.) Note that changes in the production function due to changes in technology δK_T are summarized by changes in arguments of $u(., K_T)$, rather than as a change in the u function itself. Consequently:

$\Delta u = u(.,\varphi+\delta\varphi) - u(.,\varphi)$ = change in u due to technology changes.

Holding u itself constant is simply a matter of notation, without introducing any loss of generality.

Note that CRTS=>$\mathrm{diag}(x)^{-1}u$ = constant w.r.t. x (conditionally on prices P, Ω and technology K_T). Hence there are matrices of unit input demands η_x [(L+M+N)×(L+M+N)] and η_k [M×(L+M+N)] such that

(2a) $u_x = \eta_x(P, \Omega, K_T)\mathrm{diag}(x)$, and

(2b) $u_k = \eta_k(P, \Omega, K_T)\mathrm{diag}(x)$

In the above, price vectors P and Ω are structured as follows.

P [(L+M+N)×1] = real prices of commodities and investments. Most components of P are endogenous, but import prices are exogenous. we express

$P = p + \pi$, where p = endogenous prices of output and $\pi = \pi^*$ = exogenous prices of output.

$\Omega = [\Omega_k', \Omega_T']'$ = prices of labor and capital and technology knowledge services, where

$\Omega_T = \Omega_T^*$ [(L+M+N)×1] = vector of exogenous prices of technology knowledge services (e.g., royalties) per unit output by input sector. Note that this might be endogenized in a more general model.) $\delta\Omega_T$ is a possible channel of ATP effects, namely changes in royalties Ω_T. Note also that Ω_T has already been aggregated across technologies; e.g. $\Omega_T = \Omega_{TT}\ell$ with Ω_{TT} [(L+M+N)×N].

Ω_k [M×1] = vector of prices of labor and other capital services. ω_k is mainly endogenous, but there may be an exogenous wage numeraire. We express:

$\Omega = w + \omega$, where w = endogenous prices of capital services and $\omega = \omega^*$ = exogenous prices of capital services. Since Ω_T is exogenous, $w_T = 0$.

1.3.3. The production of capital services from capital stocks

v [M×1] = vector of capital services produced except technology knowledge (but including labor and leisure time; zeros in L+N entries). $v=V(K^*) = v^*$; i.e., capital services are predetermined. Generally the functional form V(K) is assumed to be

(3) $v = \kappa K$

for some constant matrix κ of service units per capital stock. (κ is presumably diagonal and in that case contains no real content except definitions of units of account.) However, if there is slack capacity, then this expression provides only an upper bound on capital and labor services actually employed.

1.4. Consumption, income, and welfare

c [(L+M+N)×1] = consumption bundle, including government services. To simplify the exposition, demand for government services is aggregated with household demands.[19] (Government production sectors are a subset of industry sectors.) The last N elements of C are (presumably) zero because households do not demand technology knowledge services, but placeholders are included to maintain conformation of output vectors. Households are also assumed to make the investment decisions. The consumption function is $c = C(p, I\text{-}S; \psi, \tau)$ = utility maximizing consumption. τ refers to exogenous tax rates, which are incorporated into the consumption function. $\delta\tau$ refers to changes in taxes needed to support changes in ATP activities. We assume C(.) is Gorman polar form, such that

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[19] In a more complete model, taxes paid by households would be treated as parallel to household inputs of private goods and taxes paid by business would be treated as parallel to business inputs. To see how this can be justified using an optimizing median voter model, see Chou [1995].

(4) $C = \alpha(p) + \gamma(p)(I - S - p'\alpha)$,

where $p'\gamma(p) = 1$ and hence $p'C(p) = I - S$ (i.e., total expenditures equal income less savings). In the above,

$I = I^*$ = gross income. The GNP identity is

(5) $I - S = p'(x-u-j)$.

$S = S^* = p'j^*$ = exogenous gross savings = exogenous gross investment. Changes in S due to ATP are denoted δS; however since aggregate savings equals investment, $\delta S = p'\delta j$, so δS is not an independent pathway of influence.

Although not part of the CGE model *per se*, we can define

W(t) = expected welfare at time t. It can be expressed as

(6) $W(t) = \Sigma_{t'}\, w(c(t'), \psi)\varepsilon^{-R(t'-t)}$, where:

w(.) is the temporary or instantaneous utility. (w(.) is presumably maximized by C(.) and hence can be found by integrating (4) and imposing a utility metric.)
R is the social discount rate.
Since the model is quasi-static, this equation would be used to evaluate the net present social value of ATP intervention, but not to model savings or investment. (Note that the ψ dependence is redundant, in the sense that the vector of unavailable goods and services is reflected at equilibrium by 0's in the corresponding consumption vector elements.)

1.5. Exports and imports

There is no international finance sector or exchange rates. There is either a single sector or a vector of non-competitive import goods, and their prices are exogenous. (Consequently, we are abstracting away from most business cycle considerations.) Exports are determined by exogenous demand functions which depend on prices of goods:

e $[(L+M+N)\times 1] = e(p; \varepsilon)$ = exports. ε is a parameter representing effects of ATP intervention on foreign demands for US exports; hence $\delta\varepsilon$ is a contact point.

Imports are determined by endogenous demands. Since imports are non-competitive, they are determined by domestic demands in the non-competitive sectors. Effects of ATP on imports are represented explicitly as changes in the exogenous prices, and implicitly by $\delta\psi$, the change in availability of goods.

1.6. Material balance and the conditional quantity equation

Material balance for sources and uses of goods and services (including capital services) can be stated as:

(7a) $x = j + c + u_x. + e$
(7b) $v \geq u_k$

(7a) holds with equality because j includes any inventory changes. In the following we assume that capacity is not binding and ignore (7b).

Using (2), (4), and (5) we have

(8) $x = j^* + \alpha + \gamma[p'x - p'\eta_x x - p'n^* - p'\alpha] + \eta_x x + e(p)$

1.7. Price models and the price equation

1.7.1 exogenous prices, summarized

The exogenous prices have already been described. We probably need to include an exogenous wage rate in ω_k as the main numeraire. Exogenous prices of technology services (royalties) are included in ω_T. We assume $w_T = 0$ (all royalties are exogenous). The prices of non-competitive imports are included in π.

1.7.2. capital services

The price of capital services in equilibrium equals the price of investment goods times (depreciation rate plus real rate of return) divided by productivity for capital services; or

(9) $w_k = (rI + \mu)\kappa^{-1}b'(p+\pi)$, where

$r=r^*$ is an exogenous scalar real rate of interest, and
b, the capital requirements matrix, acts as projection operator which constitutes the prices of corresponding investment goods from output prices.
Note that δr^* is a possible channel of influence.
Note also that this price model may seem a bit far-fetched in the case of any "human capital services" or labor prices that are left endogenous; however, if the wage equation is rewritten in any form which depends purely on prices and not on quantities, then there will no significant changes in the following analysis.

Since the elements of K_T are 1's and 0's, we cannot use the common convention in which the price of capital stock is 1 and quantity units are in dollar expenditures. Instead, the price of knowledge capital is the cost of the marginal R&D that generated it. (This includes the cost of dead-end paths and failures. Since those dead-ends are not always paid for by the same agents that own the ultimately successful patents, there can be some accounting problems, but we will assume them away for purposes of exposition.)

With unemployment or non-equilibrating capacity, additional assumptions would be needed in this price model, and the solution algorithm given below would not work.

1.7.3 commodities

Monopolistic competition leads in equilibrium to average cost pricing of produced goods. Consequently, there are no excess profits:

$$\text{diag}(x)(p+\pi) = u_x'(p+\pi) + u_k'(w_k + \omega_k) + \text{diag}(x)(w_T + \omega_T).$$

From (2) and (9) we have

$$\text{diag}(x)(p+\pi) = \text{diag}(x)\eta_x'(p+\pi) + \text{diag}(x)\eta_k'((rI + \mu)\kappa^{-1}b'(p+\pi) + \omega_k) + \text{diag}(x)(\omega_T).$$

We premultiply by $[1/x_1, 1/x_2, ..., 1/x_{L+M+N}]$ to get the basic price equation:

$$(10) \qquad p = \eta_x'(p + \pi) + \eta_k'(r^*I + \mu)\kappa^{-1}b'(p+\pi) + \eta_k'\omega_k + \omega_T.$$

With CRTS and equilibrating capacity, this price model is not conditional on output.

2. Solving the model

A recursive solution method is:

2.1. Solve (10):

Invert (10) to get:

$$p - \eta_x'p - \eta_k'(rI + \mu)\kappa^{-1}b'p = \eta_x'\pi + \eta_k'(rI + \mu)\kappa^{-1}b'\pi + \eta_k'\omega_k + \omega_T.$$

Define φ to be a projection operator that picks out the subspace in which p is not identically zero (i.e. the endogenous subspace). Then we have

$$(11) \qquad \varphi p = \{\varphi[I - \eta_x' - \eta_k'(r^*I + \mu)\kappa^{-1}b']\}^{-1}\varphi[\eta_x'\pi + \eta_k'(r^*I + \mu)\kappa^{-1}b'\pi + \eta_k'\omega_k + \omega_T.].$$

This is not a solution per se, because the η's on the LHS are still functions of p. However, this equation can be solved rapidly by iteration, given existence of the indicated matrix inverse(s) and given certain local or global restrictions on $\eta_x(p)$ and $\eta_k(p)$ to guarantee convergence.

2.2. Given the price solution, solve (8).

An analytic quantity solution conditional on prices is:

$$(12) \qquad x = [I - \gamma p' + \gamma p'\eta_x - \eta_x]^{-1}[j^* + \alpha - \gamma(p'n^* + p'\alpha) + e(p)]$$

(This assumes however that labor and capital capacity v* are not binding. There is a more complicated equation available to account for capacity constraints, and a reasonably efficient solution algorithm does exist.)

3. Summary of contact points

The formal contact points of the CGE model with effects of ATP intervention are summarized as follows.

<u>The effects of successful innovation</u>

(T1) demands: the input demand functions for production or consumption.
$\delta u/\delta\psi$; $\delta C/\delta\psi$

(T2) goods: the vector of available market goods (which affects both production input demands and household consumption demands).
$\delta\psi$

(T3) technology rents: the prices of technology knowledge services.
$\delta\omega_T$

(T4) terms of trade: the prices of foreign import goods.
$\delta\pi$

(T5) exports: the export demand function.
$\delta E(p)$

<u>The effects of R&D and commercialization activities</u>

(T6) investments: the vector composition of investment decisions (including physical capital as well as R&D); and perhaps to some extent the aggregate level of saving and investment and the real interest rate as well.
δn; $\delta j = b\delta n$; $\delta S = p'\delta j$

(T7) fiscal flows: tax cost and expenditure vector of the ATP program being evaluated (other than any R&D expenditures included under contact type T3).
$\delta C/\delta\tau$

Note that techniques (K_T) the vector of available technology knowledge services (that is, a list of all the varieties of things we know how to make at a given point in time) can change. However this channel has no independent effects on the CGE model as specified, other than through new input demands (T1), goods (T2), or rents (T3). Hence δK_T is *not* a contact point.

4. A comment on CGE calculations using probablistic attribution

For purposes of exposition, in this section we adopt a probability interpretation of the "degree of attribution." (The same issues would arise under a "responsibility" interpretation.)

In terms of actual calculations of overall technology impacts, the existence of varying degrees of probability for each innovation leads to some real complications. Instead of a single counterfactual, we are faced with a range of counterfactuals that have probability values attached. For example, if in a single year N different technology innovations are funded by ATP, and each innovation has its own degree of attribution, then there are 2^N possible different counterfactual worlds, where each world has a unique combination of some innovations being caused and others being not caused by ATP. Moreover, each counterfactual world has a different probability of being "true." It is theoretically possible to proceed as follows:

1. calculate impacts in the CGE economy for each of 2^N counterfactual worlds
2. for each world, calculate the joint probability that it is the "true" world
3. calculate an exact expected value for the economic impact vector by calculating a weighted average over all 2^N worlds.

In practice, we also have the problem that a given innovation might occur in various different years, or in various different national locations, or in various different standardized forms. Therefore an explicit and fully detailed calculation along the above lines would certainly become intractable.

The simplest approximate calculation is to adopt a linear approximation of the CGE model. In that case, 2^N simulations can be replaced with N+1 basis simulations, and all other simulations can be represented as weighted sums of the basis simulations. Unfortunately, if ATP achieves the kind of major successes it hopes for, then the "small change - linear" approximation would not hold.

The next simplest method is a Monte Carlo approach. We would simply roll some (quasi-random, computational) dice and chose a counterfactual world according to the given probabilities; calculate the corresponding CGE model; and repeat until the sample of counterfactual worlds is "large enough." We can calculate the accuracy of this calculation using the standard deviation of the sampled impact values. Note that Monte Carlo approaches are expensive in terms of computer time; therefore it is important that the CGE model have a very efficient solution algorithm. (For that reason, the CRTS assumption underlying the iterative solution to (11) is critical.)

5. A comment on aggregation

Alternatively, NIST might reasonably decide that the actual CGE calculations are not important. That is, policy makers may prefer to focus on the vector of direct effects and their associated probabilities (i.e., bridge models and attribution models), rather than on an aggregation of total effects. In particular, the total effects (unlike the direct effects) are dependent on, and sensitive to the specification of, a particular CGE model. Also, CGE models do in fact introduce multiplier effects on top of the directly measured effects, and these multiplier effects can depend sensitively (in magnitude but usually not in direction) on the detailed specification of the model.

More likely, however, at some point policy-makers will want to see some aggregate measures of ATP's impacts on the world, so they will try to sum up the vector of direct effects. Also, the only way to determine portfolio effects (i.e. the reduction in the relative riskiness of a program as the number of independent projects increases) is to perform a probabilistic aggregation across projects. Unfortunately, the only theoretically correct way to make such an aggregation is by use of some CGE model, because that is the only way to avoid double counting (as well as to avoid certain kinds of undercounting). Again, this problem is unimportant if the effects of ATP interventions are small and non-interacting. Unfortunately, however, it is the goal of AP to have effects that are both large and interacting, for example by creating a critical mass of important and interrelated technologies.

A possible topic for future research would be attempting to partition the CGE model impact results into "direct effects" + "aggregation interactions" + "multiplier effects." In that case, a meaningful aggregation procedure which includes aggregation interactions but left out multiplier effects might be feasible.

APPENDIX 2: Counting Spillover Diagrams for 3 Agents

This appendix contains the results of some calculations on the numbers of transactions diagrams or graphs of various types when exactly 3 nodes (agents) are involved.

Under the rules given in Chapter 5, with 3 agents the minimum number of arrows possible is 3 (because each agent must have an in-arrow), while the maximum is 9 (because an agent can have no more than 3 out-arrows.) Table A2.1 shows calculated counts of distinct diagrams of various types, using the following categories.

"Unilateral Spillover" refers to knowledge, material, or fiscal spillovers. These spillovers are unilateral, in the sense that they are not necessarily a direct part of any market exchange or network exchange relationship. These three types of spillover are symmetric: interchange of arrows of any two types in a valid diagram yields another valid diagram. Consequently, there are many symmetry rules on numbers of distinct unilateral spillover diagrams. For example, the number of diagrams containing knowledge spillovers equals the number containing material spillovers and the number containing fiscal spillovers. Also, the number of diagrams containing market, network, and knowledge spillovers equals the number containing market, network, and material spillovers.

"Linear graphs" are diagrams in which two of the agents have no arrows connecting them directly. "Triangular graphs" are those in which each pair of agents share at least one arrow. This distinction is significant because linear transactions can't include a network spillover; therefore under the rules in Chapter 5 they must include a market spillover. Also, triangular graphs that don't include a market spillover must include a network spillover that is based on unilateral spillovers.

The "pattern of arrows" lists the numbers of arrows connecting each pair of nodes in the graph, starting with the highest number. As it turns out, with 3 agents no more than three patterns are possible for any fixed number of arrows, with at most two triangular patterns and at most two linear patterns.

Table A2.1
Catalog of 3-Agent Transactions
(Counts of distinct graphs)

		With unilateral spillovers				With no unilateral spillovers			Total
Number of arrows	Pattern of arrows	Exchange	Network	Network+ exchange	Subtotal	Exchange	Network+ exchange	Subtotal	
Linear graphs									
0,1,2	-	0	0	0	0	0	0	0	0
3	2,1	18	0	0	18	0	0	0	18
4	2,2	18	0	0	18	21	0	21	39
	3,1	18	0	0	18	0	0	0	18
5	3,2	24	0	0	24	36	0	36	60
6	3,3	6	0	0	6	18	0	18	24
7	-	0	0	0	0	0	0	0	0
8	-	0	0	0	0	0	0	0	0
9	-	0	0	0	0	0	0	0	0
10+		0	0	0	0	0	0	0	0
Total		84	0	0	84	75	0	75	159
Triangular graphs									
0,1,2	-	0	0	0	0	0	0	0	0
3	1,1,1	11	0	0	11	0	0	0	11
4	2,1,1	27	27	54	108	0	0	0	108
5	3,1,1	27	9	54	90	0	0	0	90
	2,2,1	54	27	216	297	0	0	0	297
6	3,2,1	72	18	360	450	0	0	0	450
	2,2,2	27	11	162	200	0	38	38	238
7	3,3,1	18	3	144	165	0	0	0	165
	3,2,2	45	9	342	396	0	108	108	504
8	3,3,2	21	3	222	246	0	108	108	354
9	3,3,3	6	1	42	49	0	38	38	87
10+		0	0	0	0	0	0	0	0
Total		308	108	1596	2012	0	292	292	2304
Grand totals									
0,1,2		0	0	0	0	0	0	0	0
3		29	0	0	29	0	0	0	29
4		63	27	54	144	21	0	21	165
5		105	36	270	411	36	0	36	447
6		105	29	522	656	18	38	56	712
7		63	12	486	561	0	108	108	669
8		21	3	222	246	0	108	108	354
9		6	1	42	49	0	38	38	87
10+		0	0	0	0	0	0	0	0
Total		392	108	1596	2096	75	292	367	2463

Source: IPPBR.

APPENDIX 3: Interview Script for Phone Survey of DV Experts

PRELIMINARIES
Introduction

provide our names, the sounds of our different voices, and a brief description of our roles in the project

Explanation of interview purposes

The purpose of our interview with you is to provide data for a report that we are preparing for the National Institute of Standards and Technology's Advanced Technology Program on the Potential Economic Impacts of Digital Video Technologies.

In this phase of the project we are concerned with identifying major areas of research and development that will affect Digital Video applications in the marketplace within the next 5 to 7 years, or sooner. We have contacted you because of your expertise in _______ area of Digital Video Technology. We want to ask you questions both about this general area, and about specific applications on which you may be working.

The topics that we would like to discuss with you today fall into 4 major categories:

- First, we would like to discuss the goal or goals of the technologies in which you are involved, the methods being developed, and your assessment of their current status;
- Second, we are interested in your assessment of the likely impact of these technologies on the immediate markets for which they are being developed;
- Third, we are interested in your assessment of the effects that these technologies might have on other related markets; and
- Fourth we are interested in your assessment of the obstacles that might prevent successful development or commercialization of the technology or technologies we are discussing.

Review of procedures, etc.

To assist us in preparing an accurate account of this interview, we will be tape recording this conversation. In addition we will be taking notes during the interview.

We recognize that some of the information you provide may be confidential. Please let us know at the time when there is information needs to be kept confidential.

Once the interview is completed we will write up a report describing the interview. A copy of this report will be emailed to you and you will have a period of 14 days in which to correct any errors or omissions that you find. That is also your chance to make sure that no confidential information will be revealed in our report.

INTERVIEW

1. Technology Description

- Within the general area of ___________ (fill in technology buzz word), what specific DV related technologies are you working on or informed about.
- Let's talk about each of these briefly.
  - Could you describe for us the goal of each of these technologies?
  - What approach or approaches are being used to achieve these goals?
  - How far along would you say each technology is? That is what stage in the R&D process is it at? How far is it from commercialization?

- What are the major technological obstacles that must be overcome before ________ (Technology) can be commercialized? How would you rate the prospects of overcoming them?
- For each technology we've discussed who are the leaders in the field (academic experts, firms, laboratories)

- Of the technologies you've named, which one are you most interested in or most involved with? Let's discuss this one in more detail

2. Anticipated Effects in Immediate Markets

- What is the intended market for _____________(Technology)? That is who are the likely customers for the products that will be developed? For what purposes will they use them?
  - Are there alternative means of achieving these aims that will be replaced when this technology is available? What are they?
  - What are the advantages of ____________ (Technology)?
  - What if any disadvantages does ____________ (Technology) have?
- Looking ahead, once __________ (Technology) is developed, will it be easy for potential competitors to produce similar products?
- What other competing approaches do you expect to be developed in this market?
- Will patents, trade secrets, or other mechanisms be effective in protecting intellectual property rights in this market?
- Does the national location of innovation in __________ (Technology) matter? Will early leaders gain a critical lead?
- What factors are likely to affect the timing of key innovations in _________ (Technology)?

3. Anticipated effects in related markets

Knowledge spillovers

- Often once a technology is developed for one market it proves to have applications in other markets. Can you think of other potential end users for whom __________(Technology) might be adapted?

Horizontal, Upstream, and Downstream Complementarities

- The value of many products depends on the production of other related products. For example, the utility of personal computers is dependent on the software tools available to run on them, and the utility of particular software depends on the availability of appropriate computers. Is the value to users of __________ (Technology) dependent on the development of any such complementary products? What are the prospects for their development?
- Does solving the technical problems associated with _________ (Technology) require development of any important inputs that don't currently exist?
- Will the development of ________ (Technology) encourage the development of any new technologies for which it will be an input?

4. Obstacles to Development

Barriers to development or commercialization

- What do you see as the major barriers that might block or delay development of _________ (Technology)?

Major categories of network interactions (Some of these obviously may be inappropriate given preceding answers).

- Many Technologies involve a "chicken and egg" problem of the sort that characterizes HDTV--Transmission isn't profitable unless there are sets to receive the picture, and people don't want to buy sets until there is something to watch. Is this likely to be a problem here?

- To what extent is the utility of ________ (Technology) dependent on coordination with other actors? For example, is there a need for the development of interfaces or hardware-software standards?
- In some cases the emergence of an industry standard can result in perpetuation of an inferior technology. Do you see any danger of that happening with _________ (Technology)?
- Is the value of ________ (Technology) to consumers likely to depend on how many other consumers are using it? Is there some minimum scale of adoption that must be reached for commercialization to be effective?
- Are there synergies with other technologies that we have not yet discussed?

Concluding remarks
Thank you for you help. Goodbye.

APPENDIX 4: Partial List of Interviewees

This list includes those interviewees who did not request anonymity. Some additional interviewees specifically requested anonymity or else haven't responded to our request to publish their names.

Craig J. Birkmaier
Consultant
P-Cube Labs

V. Michael Bove, Jr.
Head of Object-Based Media Group
MIT Media Laboratory

Franz Buchenberger
CEO
blaxxun interactive, Inc.

Dr. John Gauch
Associate Professor
Dept. of Electrical Engineering and Computer Science
University of Kansas

Marc de Groot
Chief Executive Officer
Immersive Systems, Inc.

Dr. Bradley Horowitz
Chief Technology Officer
Virage, Inc.

David W. Jacobs
Research Scientist
NEC Research Institute

Dr. Ramesh Jain
Director
Visual Computing Lab
UC-San Diego

Daniel Lipkin
Principle Technical Staff
Oracle Worlds

Oracle Corporation

Terrence Masson
tman@linex.com
http://visualfx.com

Dr. Gary J. Minden
Professor, Electrical Engineering & Computer Science
University of Kansas

Moe Rubenzahl
Director of Advanced Product Planning
Videonics, Inc.

Bengt-Olaf Schneider
Manager, Graphic Systems & Solutions
IBM T.J. Watson Research Center

Alvy Ray Smith
Graphics Fellow
Microsoft Corp.

APPENDIX 5: Major Categories of the Technology Map

I. DV Content Creation, Capture, and Display

A1: Standard Image Capture And Display
Applications
Methods and devices
Standards and interoperability

A2. Specialized Image and Data Capture and Display
(e.g., stereo vision, user-controlled POV, smart cameras)
Applications
Devices
Methods and features
Standards and interoperability

B. Editing/presentation/authoring/production Technologies
Applications
Methods and devices
Standards and interoperability

II. DV Data Storage, Access, and Retrieval

C. Storage and Retrieval
Applications
Methods and devices
Standards and interoperability

D. Pattern Recognition and Related Artificial Intelligence Technologies
Specific applications
Pattern recognition subjects
Object/Pattern recognition/Computer Vision methods (see also: compression)
* *Pattern recognition: supporting hardware*
Standards and interoperability

III. Transmission and Management of DV Data Streams and Intellectual Property

E. Transmission Technologies
[segmented for countries with differing TV standards and interoperability]
Applications
Methods and devices
Standards and interoperability

F. Control of Signal, Message, and Data
Pattern-recognition-related applications
Cryptographic-related applications
Other applications
Methods and devices
Standards and interoperability

IV. End uses of DV Data Streams

G. Communications Support and Information Support
**Transmission applications*
Data provision applications
Data management applications
Methods and devices
Standards and interoperability

H. Interactive Service Technologies
Applications
Methods and devices
Standards and interoperability

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