KNOWLEDGE AND SOCIETY: THE ANTHROPOLOGY OF SCIENCE AND TECHNOLOGY

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ABSTRACT

How do technologies serve as both the products and producers of cultural meaning and power by transcribing human activity into object form? In the United States, CAD/CAM technology has political content deriving in part from a rhetoric of nationalism. The nationalist script positions CAD/CAM as improving industrial productivity by uniting activities in design and manufacturing. Translating the nationalist script into local terms, however, has produced three distinct technologies—2D drafting automation, 3D wireframe and surface modeling, and solid modeling—endowed with the agencies of three different types of users. None of the three is oriented to uniting design and manufacturing. This case study provides an example of how the American appeal to technological solutions both endows technology with agency and masks the social choices built into technological development, enabling Americans to celebrate and blame their technology instead of themselves.

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INTRODUCTION

Five engineering students were in my living room discussing the mid-term exam in their CAD/CAM class. They had been anxious going into the exam because they were unsure what to expect. The course was unlike any other they had experienced in the mechanical engineering curriculum. In contrast with courses in thermodynamics, kinematics, fluid mechanics, etc., "Introduction to CAD/CAM" did not consist of a step-by-step presentation of textbook knowledge to be learned by completing innumerable problem sets. Instead, students confronted a seemingly endless series of disconnected topics dealing with the hardware, software, and industrial implications of computer-aided design (CAD) and computer-aided manufacturing (CAM).

Despite their fears, the students were happy they took the class because it looked good on their resumes. I came to realize the significance of this point after listening to many complaints that sitting in the freezing CAD Lab learning how to use and write CAD programs required more time than any other course they had taken. Four were seniors hoping to find jobs sometime during the semester and then coast into graduation. Each believed that learning CAD/CAM rather than doing some advanced coursework in engineering science would improve their chances of finding employment in a tight job market. All were satisfied not only that industry would find this experience important but that they were involved in an enterprise of national significance.

The students did not realize, however, that by participating in this course they were joining a broader competition to shape both the future technological structure of American manufacturing and the organization of legitimate knowledge in engineering. They did not understand, for example, that there was substantial political content in the first two questions on the exam: "What is the definition of CAD?" and "What is the definition of CAM?" After watching the instructor point these definitions out in the reading, show them in a slide presentation, write them on the blackboard, and list them at the top of the review sheet, the students had wisely concluded that defining CAD and CAM was probably important. Each had written something like the following: "Computer-aided design can be defined as the use of computer systems to assist in the creation, modification, analysis, or optimization of a design," and "Computer- aided manufacturing can be defined as the use of computer systems to plan, manage, and control the operations of a manufacturing plant through either direct or indirect computer interface with the plant's production resources" (Groover and Zimmer 1984: 1-2). The instructor was more aware than the students that these definitions were good because they positioned CAD and CAM as legitimate engineering activities without making it look as though an industrial engineering course was being taught in a mechanical engineering department.

Eating my food and drinking my beer on a biweekly basis, these students helped my ethnographic field work by serving as a focus group (Krueger 1988; Stewart 1990). They understood that I am a cultural anthropologist who was originally trained as a mechanical engineer, and that I am studying the culture of computer-aided design technology. They knew that over the previous year and a half I had been observing research activities in the CAD Lab, conducting interviews at industry shows and in manufacturing plants, and following participants and developments in a joint government-industry-university venture in computer-aided design and analysis (Downey 1992b). But they did not understand well enough to explain it to someone else, nor did they particularly care. They believed it important for some kind of outsider to examine engineering, for engineers generally feel quite neglected in this respect. They tolerated me directing and tape-recording their discussions, but they had no concept whatsoever of how what I do could constitute productive work. A frequent question put to me was: "What good is it?" My answers varied from "It doesn't have to be useful to be good," to a detailed account of my utopian vision of helping engineers write features of citizenship into the self-interested personhood of corporations.

In the account below, I show that CAD/CAM technology has political content deriving in part from a rhetoric of nationalism. During the 1980s, a collection of elite engineering groups and organizations applied a nationalist script, or narrative, to elevate CAD/CAM technology, bring it into focus, and give it distinctive significance as crucial to resolving a national identity crisis. Exemplifying an American cultural predisposition toward technological determinism, this script positions CAD/CAM as a technology that will improve industrial productivity by linking design and manufacturing activities and unifying them in a coordinated, integrated, and flexible manufacturing enterprise.

However, while the narrative built into this script provides legitimacy for CAD/CAM advocates in 'public' domains by positioning CAD/CAM as a 'productivity tool,' it does not take account of the diverse identities of potential users who compete for resources and power in design and manufacturing. Translating the nationalist script into local terms has produced three distinct technologies—2D drafting automation, 3D wireframe and surface modeling, and solid modeling—endowed with the agencies of three different types of users. Each technological development abstracts informational content from different engineering activities, transcribes the information into binary code, and then inserts the resulting technology back into those activities. None of the three outcomes is oriented to uniting design and manufacturing. This case study provides an example of how the American appeal to technological solutions both endows technology with agency and masks the social choices built into technological developments, enabling Americans to celebrate and blame their technologies instead of themselves.

ANTHROPOLOGY OF TECHNOLOGY

In the United States, the natives tend to understand and characterize technology as an external phenomenon, or more particularly as an autonomous force (Teich 1990). From this perspective, technologies develop according to their own technical logics within specialized technical communities whose deliberations are essentially opaque and presumably free of cultural content. American images of the past, present, and future regularly script technology as an independent variable in relation to society as a dependent product.

For example, we Americans remark with wonder how the automobile has transformed our landscapes, democratizing the single family home and introducing suburbia between urban and rural environments (Perin 1977). We are alternately enthusiastic and frightened at what we call "the impact of the" computer as it blurs the boundaries of our personhood by reconstructing us as information, forcing us to reconceptualize what it means to communicate, to have privacy, or to leave home for work (Dunlop and Kling 1991). We also argue regularly over technology, debating such things as whether the nation should rely upon nuclear power or solar power for its energy supply. Some Americans believed that nuclear power will produce a police state and solar energy a democratic utopia while others believed that nuclear power promised energy too cheap to meter and solar power a return to the Dark Ages (Kaku and Trainer 1982). Few people, however, questioned the presupposition that the technological form determined the social form.

Through most of its history, the discipline of cultural anthropology has reproduced this cultural assumption in its everyday work. I leapt from undergraduate studies in mechanical engineering to graduate work in cultural anthropology during the mid-1970s in order to understand how and why Americans were so divided over nuclear power technology. The problem seemed like a cultural one to me. Yet what I learned initially was how to externalize technology from cultural accounts of human action.

Working under symbolic anthropologists David Schneider and Marshall Sahlins, I learned variants of what was arguably the dominant approach to culture at the time (Ortner 1984). I learned to see and write about cultures as bounded wholes, either as "systems of symbols and meanings" (Schneider 1968, 1969) or as "meaningful orders of people and things" (Sahlins 1976). Methodologically, I learned to identify cultural meanings on the model of a linguistic grammar, i.e., as distinctions or categories presupposed by different actors across a range of contexts. That is, just as all speakers of English presuppose English grammar in everyday speech, so all "members" of a culture presuppose its symbolic structure in their everyday actions. The study of meaning, from this point of view, was a search for shared presuppositions. One could not account for intracultural differences or variations until one had outlined sharedness. In fact, identifying differences without accounting for them as differences was a necessary step in making plausible claims about sharedness.

Nothing in the images of cultures as bounded wholes overtly prevented one from accounting for technologies as systems of symbols and meanings or meaningful orders of people and things. Yet I was puzzled by widespread disinterest in technology within symbolic anthropology specifically and cultural anthropology in general. The occasional anthropologist might point out that some group's key symbols were presupposed not only by its kinship or religious activities but by its technological artifacts as well. But much more frequently I encountered the view that technology was boring, i.e., significantly uninteresting in conceptual terms.

Anthropological works that focused on technology tended to fall into two general categories, each treating technology as an exogenous variable. The first offered variations on the theme of materialist reductionism, viewing technological development as the prime mover of all cultural change. The most prominent example was Sahlins' first mentor, Leslie White, who had advanced the general theoretical position that "the technological factor is the determinant of the cultural system as a whole" (White 1949: 366). The second category offered case studies of the impact of Western technology in "developing" societies. The most celebrated was Lauriston Sharp's (1952) story of how the presence of steel axes among the aboriginal Yir Yoront "hack[ed] at the supports of the entire cultural system" (1952: 88). A close second was Pertti Pelto's accounts of how introducing snowmobiles in the Arctic brought about "sequential transformations in economic, social, and other aspects of culture" (Pelto and Muller-Wille 1972: 199; Pelto et al. 1968). By positioning technology outside of society, these approaches did not help me understand the meanings of technology within society.

I came to believe that cultural accounts of technology within society did not exist because examining the cultural meanings of technologies undermined the assumption that cultures are bounded wholes. Given the raging debates that had been taking place internationally over technology during the 1960s and 1970s, and the huge literatures that had developed over whether technology was a dominating force, a progressive force, etc., it would have been grossly incomplete to try to characterize technologies only in terms of those meanings that were shared culture-wide. It was not enough to say, for example, that nuclear power is a category of tool, is involved in means-ends relationships, etc. The critical question about nuclear power was: how could people, even reputable scientists, disagree so systematically and violently about it? Images of technology within society raise questions about contrasts in interpretation and diversity in meaning, which cannot be answered by conceptual frameworks that account only for sharedness.

A temporary resolution of this problem was to shift my focus away from nuclear power technology and onto the groups engaged in conflict over it. This conceptual move was a subtle but significant shift away from an anthropology of technology to an anthropology of controversies over technology. I was able to account for differences in the nuclear power controversy as confrontations among bounded ideologies that had long-established traditions of their own and had been constructed from common American cultural presuppositions (e.g., Downey 1986a, 1986b, 1988). This partial step missed a great deal of the diversity.

Things have now changed. Over the past decade, the conceptual map has been redrawn and the anthropology of technology need not be so hampered. Theoretical developments in both cultural anthropology and the sociology of technology now render all aspects of technological development eminently susceptible to anthropological inquiry. In the first place, in concert with the more generalized shift in the social sciences from structure-based to agency-based approaches, cultural anthropologists are asking less about how cultural structures shape action and more about how agents construct culture (e.g., Marcus and Fisher 1986; Handler 1988; Clifford 1988; cf. Downey 1992). Assuming that cultural categories are shared uniformly across a given community is no longer acceptable. Diversity in the attribution of cultural meaning is more likely the rule than the exception. The achievement of stabilized categories by a given community is a social accomplishment to be accounted for rather than assumed. The distribution of power relations and identities across a community is integral to the process of meaning construction rather than simply a final outcome. Finally, as a flurry of recent work indicates, including this volume, anthropologists are now examining the construction of culture within knowledge-based communities (e.g., Traweek 1988, Hess 1991).

Secondly, an extensive literature in the sociology of technology has developed over the past several years, reconceptualizing technology through at least two key conceptual moves. Through the first, technological form is recast from an autonomous force to the product of social judgment. For example, John Law's (1987) concept "heterogeneous engineering" has gained wide currency to describe technological developments as the convergence of heterogeneous mixes of factors and considerations rather than a linear technical logic (see also Bijker, Hughes, and Pinch 1986; MacKenzie and Wajcman 1985; MacKenzie 1990). The second, more radical, move is to bring technological artifacts themselves into the arena of social action as active participants. That is, if technologies are constructed by social judgments, then the objects themselves contribute to shaping human action, not as autonomous forces but as socially-significant objects whose positioning in society endows them with the trappings of agency. For example, Michel Callon's (1986) influential research on the electric car has shown how production of the vehicle constructs a whole new environment of research programs, manufacturing systems, and government regulations within which the vehicle could function (see also Latour 1987; Law and Callon 1989; Star 1990).

Drawing from these developments, I advance the following question as central to an anthropology of technology: how do technologies serve as both the products and producers of distributed cultural meaning and power by transcribing human activities into object form? With the phrase "distributed cultural meaning and power," I am still referring to categories presupposed in action but with a sensitivity to category differences across communities and contexts and to corresponding distributions of power. I borrow the term "transcribing" from the activity of transcribing audio tapes, in the sense that, while transforming words or cultural objects from one channel to another, the transcription preserves certain relationships among the words or objects transformed. For example, we can describe computer technologies as transcribing human activities by abstracting their informational content and translating it into binary code. Finally, with this general question, I do not mean to reify technology or suggest a sharp distinction from science. Rather because so many groups build so many strategies and so much significance around technological categories, I simply believe that inquiries into the construction of strategies and significance categorized as "technological" warrant significantly expanded attention (see also Traweek 1988, Chapter 2; Bucciarelli 1988).

To begin to grasp the distribution of meaning and power through the construction of CAD/CAM technologies, I trace the development and implications of what I call their "positional identities." I use this concept simply as an extension of structure-based symbolic anthropology to the realm of agency, to characterize how cultural objects endowed with agency move themselves around in relation to other such cultural objects by positioning and repositioning their identities. With the term "identity," I thus refer to the sets of symbolic categories that serve to distinguish actors and other cultural objects from one another. For example, the identities of CAD/CAM 'students'[1] derive significantly from being distinguished from CAD/CAM 'faculty.' Also, CAD/CAM technologies have variable identities depending upon how these act and are categorized in relation to people and other technologies.

I use the modifier "positional" to bring identities to life as both a condition and a product of action. For example, the CAD/CAM instructor repositioned the identities of CAD/CAM students by bringing them in relation to CAD/CAM technology in a way that would make them spokesmen for his image of the present and future of the technology. In similar fashion, constructing distinct CAD/CAM technologies by transcribing the activities of distinct classes of users both positions them and endows them with agency among such users.

LEARNING CAD/CAM AS POSITIONING ONESELF

For students in "Introduction to CAD/CAM," learning about CAD/CAM meant positioning the technology with respect to their developing identities as prospective engineers.[2] Since the course was in engineering, this entailed, at minimum, internalizing technical categories that have stabilized in the field. Such categories both distinguish CAD/CAM from other technologies and map out its internal components in technical terms. For me, the organization of topics in the course was useful because it provided evidence about the relative stabilization of different categories.

The instructor taught these distinctions by offering formal definitions, such as the definitions of CAD and CAM included on the mid-term exam. I learned the significance of this strategy when I later questioned it in an informal discussion with the instructor. Trying to avoid anthropological jargon, I argued that one cannot teach culture with definitions since cultural distinctions are presuppositions implicit in action rather than labels that stand in one-to-one relationships with objects. She responded by pointing out that the definitions in her course were overly rigid only because the field is in flux and by maintaining that definitions provide a useful tool for orienting unfamiliar students. I realized that a goal in this field, and probably in other fields of engineering and science, is to construct categories that can indeed serve consistently as labels for distinct objects and characteristics, such that the distribution of labels stands in one- to-one correspondence with the distribution of significant distinctions among objects. Hence, even though these categories/ labels may be rigid or incomplete, engineering students accept them both as a goal and as a legitimate mode of instruction.

The students learned first to distinguish between 'interactive computer graphics' and 'CAD/CAM.' According to the instructor, this distinction is important because not making it classifies a field of engineering as a subset of the discipline of 'computer science.' To CAD/CAM people in engineering, computer graphics is a computer science activity that involves creating, storing, and manipulating models and pictures of objects via computer. For example, virtually all television logos today consist of representations by computer graphics. Interactive computer graphics differs by allowing users to control the features of graphical pictures, such as size, color, lighting, shading, with 'keyboards' or other 'input devices.'

Engineers using CAD/CAM systems indeed produce models and pictures of objects, but they also need the 'pictorial' representation to be transcribed into a 'mathematical' representation that is defined in engineering terms and stored in computer memory. For example, whereas an advertising agency may present a beautiful, computer-generated image of an automobile in order to capture prospective buyers, engineers are more concerned that the image comes with appropriate mathematical data so they can add to it evaluations from the relevant categories of engineering knowledge. Simply using the computer to produce an image of an object is not the same to an engineer as generating an engineering 'data structure' about the image.[3]

The key lecture, "Capabilities of Current CAD/CAM Systems," structured the bulk of the course by surveying the major categories of CAD/CAM characteristics. To be complete, the list of topics included a dozen items, but it was clear to all that the class was built around the categories '2D,' '3D wireframe,' '3D surface modeling,' and 'solid modeling.' These categories all designate forms of 'geometric modeling,' or the process of representing images with data drawn from the mathematics of 'geometry,' e.g., data about 'points,' 'lines,' 'circles,' 'cubes,' 'spheres,' etc. Students understood these categories as a taxonomy to be memorized. Only towards the end of the course, or possibly as graduate students, or even as working engineers would they come to appreciate that these technical categories also served to distinguish contrasting networks of developers and users.

NATIONALISM BY CAD/CAM

Few Americans realize that the sharp separation they experience between technology and society is an historical accomplishment. It is an irony of American culture that this fixed separation grounds a social commitment to technology as the solution to social problems. For example, the distinction helps grant engineers the authority to abstract 'technical' problems from 'social' problems, to attempt to solve them in the rarefied realm of technical discourse according to localized considerations reserved for that realm (e.g., 'logical' coherence), and then to apply the technical 'solutions' back to society. Engineers can boast that many problems have technical solutions and then complain about the barriers thrown up by a purely social 'politics,' as when they frequently say, "It's all politics."

Throughout my fieldwork, whether in the classroom, at industry shows and conventions, in interviews, or in reading articles, reports, and other documents, I regularly heard CAD/CAM proponents claim that developing the technology was somehow crucial to the future of the American nation, which otherwise was at risk. For example, a 1986 article in Business Week outlined efforts to integrate computer-based design and manufacturing in United States industries, under the title "High Tech to the Rescue" (Port 1986). By interviewing authors and tracing bibliographic trails of references, I identified a flurry of formal reports written by elite groups in industry, government, universities, and professional engineering societies that made public appeals for national initiatives in technology developments such as CAD/CAM, directly linking their success to the nation's future welfare. These included, for example, reports by the President's Commission on Industrial Competitiveness (1985, 1987), Congressional Task Force on High Technology Initiatives (U.S. Congress 1984, 1986), National Commission on Excellence in Education (1983), National Research Council (1985), Council on Competitiveness (1988), Business-Higher Education Forum (1983), and several professional engineering societies, such as the American Society of Mechanical Engineers (1986) and Institute of Electrical and Electronics Engineers (Christiansen 1987). Also, a large literature of articles and books written by individuals, such as Simon Ramo's (1980) *America's Technology Slip,* elaborate the point. The collective goal is to produce new technologies; the primary reason is to beat Japan.

Many of these documents present a common rhetorical strategy, a narrative in three steps. The first step is to assert that America is threatened by economic defeats at the hands of international competitors, especially Japan. This step repositions our understanding of the 'nation' by subordinating its 'political' and 'military' content to its 'economic' content. "Our nation is at risk," announced the National Commission on Excellence in Education (1983), for "our once unchallenged preeminence in commerce, industry, science, and technological innovation is being overtaken by competitors throughout the world." Americans are in a race, not as individuals, but as a collectivity. "[T]oday we no longer can assume we are ahead," writes Simon Ramo, "for [c]ontrary indications are all about us in the form of European and Japanese cars on our streets and foreign-made television sets and tape-recorders in our homes." "Evidence is building," he continued, "that these trends are the result of some fundamental patterns that cannot be changed overnight" (Ramo 1980: 8).

The second step is to isolate 'productivity' in 'manufacturing' as the problem. According to a joint industry-university report on 'competitiveness,' for example, "Much of the U.S. failure to exploit technology for commercial advantage lies in not adequately appreciating the importance of manufacturing . . . " (Council on Competitiveness 1988). The report goes on to claim that foreign manufacturers beat American companies not with low wages but with "more efficient" manufacturing processes. Claims are frequently made that "productivity has stalled" (Dimancescu and Botkin 1986: xvii) or that it "has now dwindled to small oscillation around zero" (Ramo 1980: 9).

The third step is to categorize new technologies as the means for increasing productivity, along with societal innovations deemed necessary to achieve such development. The Council on Competitiveness (1990: 1) again: "The effective development and deployment of technology is critical to America's ability to compete in world markets." Also, the Aerospace Industries Association of America (1987: 5) concluded a report on the future of the industry: "In the aerospace industry, technology development is the key to international competitiveness." Similar stories appear in such industries as consumer electronics, semiconductors, superconductors, and pharmaceuticals. In parallel with pleas for technological development are calls for cooperative R&D

ventures among government, industry, and universities (Dimancescu and Botkin 1986), as well as new government policies for patents, antitrust regulation, and international trade.

Within this narrative, it does not matter that it is difficult to measure productivity in industry, i.e., the output of product per unit labor, for all but the most repetitive tasks. The narrative also directs attention away from more radical challenges to the institutional forms of industry, government, and universities. Linking 'productivity' to an economic interpretation of the American 'nation' transforms the meanings of both at the same time. For this rhetoric of nationalism, productivity gains national, rather than purely economic, significance, and the nation gains a new form of technological salvation.

Coming as it does from elite, official groups, the rhetoric of nationalism offers a source of legitimacy to CAD/CAM proponents if they can transfer to their technology the quest for increased levels of production with improved quality at competitive costs. Judging from surveys of technical publications (e.g., Acland and Lane 1982) and histories written by early developers (e.g., Chasen 1981), this nationalist reinterpretation of productivity may have played an important role in distinguishing CAD/CAM technology from computer graphics as a "productivity tool" between 1977 and 1982. Prior to 1980, CAD/CAM had been understood as one component in the field of computer graphics, and few technical papers even used the term CAD/CAM. Beginning about 1980, however, CAD/CAM became known as the appropriation of computer graphics for industrial productivity, and technical problems became reframed against this wider objective. A key step came in 1980 when Computervision, the leading early CAD/CAM vendor by far, published *The CAD/CAM Handbook*, announcing that

> In the short span of ten years, a new technology has evolved which has already dramatically changed the way in which products are designed and manufactured. In the decade which lies ahead, advances to this echnology will benefit all by improving mankind's standard of living and quality of life. The technology is CAD/CAM and the benefit is increased productivity (Machover and Blauth 1980: Foreword).

While conducting interviews in industry and universities, I saw this book centrally displayed on many bookshelves. Without exception, interviewees agreed with the engineer at one company who told me: "That book really helped me get oriented."

Yet the realization of CAD/CAM technology has shifted its identity away from the nationalist image. The detailed work of endowing CAD/CAM with the agency of engineers by transcribing their activities into the medium of computer graphics and then inserting the resulting technology back into those activities also engages the diverse identities of technical groups in design and manufacturing who are positioned in competition with one another. As the nationalist script has been translated into localized searches for productivity, the determinist dream of CAD/CAM-induced integration between design and manufacturing has lost some of its rhetorical power. Rather, as we can see by exploring the activities transcribed into CAD/CAM technologies and thus represented by them,[4] the development of CAD/CAM positions it to empower the CAD side of the CAD/CAM division.

2D DRAFTING AUTOMATION

By far the most successful effort at transcribing design-related activities into computer graphics technologies has been to automate drafting. Engineers understand drafting as the process of producing engineering drawings, which typically represent product parts in terms of 'views' in 'two dimensions,' following mathematical rules of 'descriptive geometry.' For example, an engineering drawing of an automobile part might present how it looks from the 'top view,' 'front view,' and 'right side view' (e.g., Dent et al. 1983). Engineering students learn drafting techniques in the freshman year and apply these in senior-level design projects. They are aware of a category of worker in industry called the 'draftsman,' who takes sketches and preliminary design drawings from engineers and produces detailed drawings to send along to manufacturing. They see draftsmen as technicians who lack the four-year professional degree in engineering.

The automation of drafting has been constructed on the image of a draftsman working at a drawing board. As one developer of 2D technology recently wrote: "With a [2D] program, we start off looking at it as a model of a draftsman at a board" (MicroCAD News Staff 1990: 25). In other words, the developers and users position 2D technology as a 'drafting tool,' interpreting it in terms of the categories that give meaning to drafting practices.

Transcribing drawing practices into computer graphics and then injecting the computer graphics back into everyday drawing activities does indeed reposition the identities of everyone involved. For example, positioning 2D technology means replacing such drafting instruments as 'T-squares,' 'triangles,' 'compasses,' and 'French curves' with various types of 'input devices' (keyboard, mouse, etc.), 'display devices' (various types of cathode ray tubes, or CRTs), 'output devices' (printer, plotter, etc.), and 'manuals' for 'hardware' and 'software' (e.g., Groover and Zimmer 1984). I was first struck by these differences when I learned that pencils were not even permitted in the CAD Lab because of concerns that eraser fragments could damage the equipment.

Furthermore, rather than manually drawing points, lines, circles, and curves or doing 'lettering,' 2D technology understands these as categories of graphical 'entities' composed of graphical 'primitives' and 'attributes' that are related to one another and managed by combinations of programmed 'transformations' and 'control routines.' For example, portions of a 2D representation may be moved through 'rotation' (turning), 'scaling' (zooming in and out), or 'translation' (linear movement) functions. In short, draftsmen become 'users' who produce computer programs that output drawings rather than make drawings themselves.

In order to make the draftsman's transition from drawing to inputting as easy as possible, the 2D software transcribes the primitives, attributes, etc., back into options and commands that reproduce old distinctions among points, lines, circles, texts, etc., to a maximum extent possible. Draftsmen do not have to 'write' their programs as lines of code. In the midst of transforming draftsmen's identities and drawing practices by positioning computer hardware and software between draftsmen and their drawings, 2D technology seeks to maintain significant continuities in those identities and practices by finding ways to reproduce existing categories. In fact, many of the battles among such competitor 'packages' as AutoCAD, Generic CADD, VersaCAD, and CADKEY are precisely competitions to produce the best transcriptions of 2D drawing activities.

A crucial feature of the positioning of 2D technology has been its relation to changing computer hardware. 2D technology has been able to take its place alongside draftsmen because its activities have been structured in terms of the computational strategies and capabilities of 'personal computers.' In other words, the repositioning of computer processors from 'mainframes' (large, expensive central computers with many attached users) to personal computers transformed the identity of 2D technology from a CAD/CAM technology in large companies only to one accessible even to single users in the smallest of firms.

At first glance, automated drafting appears to fulfill the nationalist script, for it arguably increases the productivity of drawing labor. 2D programs can increase dramatically the speed of repetitive tasks, such as making changes to drawings. As the 2D developer quoted above put it, with 2D CAD "you're not so much improving the pencil as improving the eraser—the editing process" (MicroCAD News Staff 1990: 25). Articles and reports from industry routinely announce productivity increases of from 3:1 to more than 10:1.

A recent survey of industrial users showed that the majority of all CAD work is in 2D (The Anderson Report:1990). This can be seen, for example, from what a market research firm called in 1990 "The Autodesk Phenomenon." Autodesk is a vendor of software whose principal product, AutoCAD, automates 2D drafting. According to this firm, AutoCAD "now represents approximately one out of every four legally installed CAD seats worldwide," or approximately a quarter of a million drawing stations (DataQuest Incorporated 1990: 6). Industrial companies of all sizes have added 2D CAD/CAM technologies to their drafting activities. Furthermore, networks of developers and users reproduce themselves through a proliferation of magazines (e.g., MicroCAD News), users' groups and publications, and industrial shows and conventions (e.g., Design Engineering Show, National Computer Graphics Association).

Despite its success in the marketplace, drafting automation does not encourage the integration between design and manufacturing that the nationalist script imagines. In the first place, drafting automation transcribes CAD activities only. That is, it consists of people and things producing drawings on the 'design' side of product development in industry, not those involved in translating drawings to run machines on the manufacturing side. The model of a draftsman at a board does not capture manufacturing practices. In addition, 2D technologies do not capture other design activities beyond drafting. Evidence for this comes from the fact that, in contrast with the other CAD/CAM technologies, university researchers and government funding agencies have had little involvement in their development. Also, while students in the CAD/CAM class learn 2D technology, they come to view it somewhat impatiently as a necessary steppingstone to more interesting material. They would not consider it appropriate for a senior course merely to reproduce a freshman course on the computer.

In addition, the implications of 2D developments for power relations within the firms that use them are complex and variable, and such issues are frequently hidden behind the overt rhetoric of calculating productivity. For example, in one firm I have observed, engineering managers sought to maximize the output of expensive CAD equipment by having operators use it two or three shifts a day and on weekends. The effect was to separate CAD activities and personnel from the other design activities of weekday engineers. Also, competition between draftsmen and engineers for use of the CAD equipment was high until the engineers obtained additional equipment that was more suited to some of their advanced interests. A number of sympathetic critics have pointed out that CAD users sometimes become more isolated from other design personnel and that managers have more difficulty monitoring CAD activities. As a result, tensions that can inhibit acceptance sometimes emerge (Reinschmidt 1991). Also, it is instructive that little data are available in company reports and publications concerning changes in the demand for draftsmen. Hacker (1990: 175-94) argues that 2D drafting automation contributes to the deskilling of engineers as operators and their technologies appropriate more and more of the engineers' capabilites. However, her work does not explore the implications of developments in 3D modeling.

In any case, it is clear that 2D CAD/CAM appears incomplete from the perspective of the nationalist script because its content orients the user away from integrating design and manufacturing. Also, the translation of technology-induced national productivity into local calculations of the productivity of drawing labor tends to obscure other issues, scripts, and identities that also shape the construction and use of 2D CAD/CAM.

3D WIREFRAME AND SURFACE MODELING

The technologies of 3D wireframe and surface modeling are constructed on a different image than the draftsman producing two-dimensional views. 3D technologies transcribe into computer graphics geometric 'models' of discrete objects in three dimensions. Rather than being drawing-oriented, 3D technologies are object-oriented. What makes 3D graphical representations so significant is that they can be linked to other engineering activities beyond drafting that make up the design process.

Wireframe models and surface models construct 3D representations of objects with different categories of geometric information. The differences between these categories position the 3D models in somewhat contrasting ways with respect to both engineers and computers; however, these positions overlap sufficiently for me to present them together. That is, wireframes and surface models have different identities as CAD/CAM technologies, but both contrast significantly with the identities of 2D technology and solid modeling.

A wireframe representation constructs an object as a collection of lines depicting the objects 'edges' (Groover and Zimmer 1984: 59-61). Picture, for example, a visual image of an automobile portrayed only by all the edges of its many components. Geometrically, the wireframe presents information about the car as a set of points connected together in 'three dimensional space.' It effectively extends a 2D drawing of points and lines into a third dimension. Engineers characterize the wireframe by saying that it "knows" nothing more about the car than these points and lines.

The extension from 2D to 3D transforms a drawing into a model because it adds a great deal of engineering information to the representation. Engineers can view the object from any perspective and inquire into whether particular components interfere with one another. They can use the point and line 'data' to calculate the object's 'volume,' 'weight,' 'center of gravity' (location of the balance point) and 'moments of inertia' (a measure of how easy it is to rotate the object in different directions; e.g., it is easier to roll a car over sideways than end over end).

Adding these different kinds of information to the geometric representation or model is called 'doing analysis,' which constitutes a significant proportion of engineering activities in design (Eide et al. 1986: 7-8). In doing analysis, engineers add to the graphical image by inserting it into theoretical systems of forces. These systems of forces are categorized according to the distribution of disciplines and subdisciplines in academic engineering. For example, one engineer at an aerospace firm reported to me that his design group included a 'stress man,' whose job was to calculate the stresses (physical push or pull) that objects experience when subjected to external forces. Other analysis activities include such areas as 'heat transfer' (how objects respond to heating or cooling), 'kinematics' (how moving parts interact with one another), and 'fluid dynamics' (how air, water, or other fluids behave when moving). Students in the CAD/CAM class had all taken courses devoted to each of these areas. They learned that the activity of doing analysis varies significantly from industry to industry and product to product.

A wireframe model is limited, however, to interacting only with those analysis activities that make use of points and lines, while surface models intersect with a much greater range of analysis activities. A surface model represents an object as a set of curved surfaces. Picture, for example, an automobile portrayed not as a set of straight lines but as a set of curved surfaces. Now picture shading these surfaces to give the exterior a sculptured look. The surface model is much more complicated mathematically because, in order to represent surfaces, it translates geometric data about points into 'algebraic' equations about curves and then links these equations together. Do you remember from ninth grade, for example, the 'second-order polynomial' $ax^2 + by + z = 0$? Raise the variables to powers as high as six or ten and you would begin to approach the level of complexity represented in the data structures of surface models.

Although constructing a surface model requires far more calculating time on a computer than a wireframe, it intersects with a large number of analysis activities that build on information about surfaces. For example, calculating how fast an object might heat up or cool off requires applying theories of heat transfer. Students learn in their heat transfer class that these theories link heating and cooling to 'surface area,' which is a geometric concept. Perhaps a parent has told you at some point, "If your feet are cold, put on a hat." Heat transfer theory reconstructs this as: "Reduce the amount of surface area exposed to the temperature difference to reduce the rate of cooling." A surface model provides the algebraic equations to link the geometric representation to heat transfer analysis, allowing the engineer to reshape the design based upon the results of analysis. More generally, by linking the geometry to different categories of analysis, 3D surface model technology makes it possible to consider more than one type of analysis simultaneously, thereby concentrating more and more design functions at earlier and earlier points in the design process.

Since 3D wireframe and surface modeling technologies link with analysis activities, they are oriented much more to activities in research and development (R&D) than to drafting. For example, for over a year I followed the development of a joint venture among a university, a government agency, and seven aircraft companies whose purpose has been to improve the analysis activities of engineers evaluating potential design concepts for aircraft by representing these concepts in terms of sophisticated wireframe and surface models (Downey 1993). The contrasts with 2D CAD/CAM are stark. The engineers seeking to make use of wireframe and surface modeling were already devoting much of their time to doing analysis on the computer. The 3D technologies were added to these existing activities rather than replacing them. As a consequence, the burden of developing the programs in wireframe and surface modeling fell much more on the shoulders of the user engineers than is the case with 2D technologies, in which vendors compete to sell 'packages' to draftsmen. The engineers involved in developing the geometric models to be used for aircraft design strongly resist the notion that they are producing a package.

Evidence for the different positioning of 3D wireframe and surface modeling also comes from other sources. Much of the research on 3D modeling itself has taken place within industries, especially the aerospace and automotive industries, that have large R&D organizations confronting highly complex geometries and analysis problems. Developments by university researchers may be duplicated within these industries, which do not publish or advertise their activities. In addition, although the networks of developers and users are sometimes reproduced through users' groups (e.g., graPHIGS Users' Group), magazines tend to give way here to technical journals, and shows and conventions to professional conferences and workshops. Students in the CAD/CAM class enjoy most working with this technology, since it reproduces the knowledge they gained in their engineering science courses while focusing their attention on product designs.

Finally, just as introduction of the personal computer repositioned 2D CAD/CAM among draftsmen, so more recent developments in 'engineering workstations' (e.g., by SUN, IBM, Silicon Graphics, Hewlett Packard) link 3D CAD/CAM to increasingly broad networks of developers and users. Both developers and users are intensely interested in the capabilities of these workstations, which offer enhanced capabilities for graphical representation. For example, The Anderson Report sells annual guides to new workstations for about $800. The computational abilities of workstations priced below $100,000, which is frequently a threshold of accessibility among sophisticated users, approach or surpass those of earlier mainframes, which may have cost one to two million dollars, or more. Workstations thus link the visual activities of wireframe and surface modeling with the computational activities of engineering analysis.

Although 3D technologies transcribe activities that extend beyond drafting into other design practices, in terms of the rhetoric of nationalism wireframe and surface modeling are CAD activities rather than CAD/CAM activities. That is, while 3D technologies may transcribe a greater number of design activities, they do not intersect significantly with or transcribe manufacturing activities. Once again the focus on productivity becomes a highly localized calculation and enhancement of engineering analysis. Analysis problems vary as widely as do categories of engineering knowledge, and each area has developed its own mathematical techniques, frequently varying not only from industry to industry but also from company to company. Assessing the implications of 3D CAD/CAM for national productivity becomes an even more difficult, and more contested, calculation than assessing 2D technologies. In fact, far from realizing the nationalist agenda by unifying design and manufacturing activities and personnel, successful developments in 3D wireframe and surface modeling have raised suspicions and fueled concerns in manufacturing circles.

SOLID MODELING

Similar to the wireframe and surface models, the solid model is constructed with an object orientation. It represents the object as a solid, using one of two methods. The first is called 'constructive solid geometry,' which builds models by adding and subtracting 'primitive' solid forms, such as 'spheres,' 'cubes,' and 'rectangular solids.' Picture, for example, a model of an automobile constructed of chunks of spheres and cubes. For example, one might construct a door with a window by using one rectangular solid to represent the door and then subtracting another rectangular solid to make the window.

The second method is called 'boundary representation.' It distinguishes points 'inside' an object from points 'outside' by defining the exterior surfaces of the object as the 'boundaries' of a 'closed volume.' This method is more difficult to visualize. Remember the surface model of an automobile we constructed earlier? If we used that image only to define the overall shape of the vehicle for aesthetic and/or aerodynamic purposes, we do not need information between the surfaces, or inside the vehicle. The surface model is just a bunch of surfaces that may or may not be connected together. To convert a surface model into a solid model, we now need to link all surfaces together and then calculate the volume of space produced inside. Picturing the automobile again, a boundary representation model breaks it down into its many components, each represented as a closed volume.

On several occasions, I have heard solid modeling represented as the perfect link between design and manufacturing. From a geometric point of view, writes one advocate (Barlow 1990: 20), a solid model of a "real, three-dimensional physical object" is "complete, valid, and unambiguous." That is, the object contains information not only about points and lines or about surfaces but also about the interior structures of product parts. A solid model is very useful for making sure that product parts have enough space after these have been designed, i.e., for 'interference checking.' Seemingly, presenting such a complete set of geometric information would also link solid modeling to the manipulation of parts in manufacturing processes. An interviewee at a national engineering design show criticized all the research going into 2D drafting and 3D wireframe and surface modeling by saying, "Everybody should be working on solid models."

However, solid modeling technologies do not transcribe very extensively the activities of either engineering design or manufacturing. On the design side, solid models do not intersect easily with analysis activities because they are very difficult to modify in light of the results of analysis. For example, the engineers in one small company I observed were very interested in solid modeling because the company makes many different metal parts with varying sizes but roughly the same geometry. They hoped for a solid modeler that would provide a basic design configuration and that they could modify slightly for each application. One engineer proudly told me he had written a solid modeler himself. He added, however, that neither it nor the expensive solid modeler the company had purchased from a large CAD/CAM vendor was flexible enough to reshape proposed designs after engineers had analyzed them. Another engineer said that, when he called the vendor to complain about its solid modeler, he was told, "You're not actually using it in production, are you?" Echoed another researcher recently (Zuffante 1990: 42), "Conventional solid models are so difficult to modify that users have typically worked in another medium such as engineering drawings until the design has stabilized." Finally, I also watched as students in the CAD/CAM class became very frustrated during their lab experience with solid modeling, for the work of producing solid models seemed endless yet it also seemed to many as little more than "glorified drafting," i.e., it drew pictures without linking to analysis activities.

On the manufacturing side, the object orientation of solid models orients users of it away from a large range of manufacturing activities. Among manufacturing engineers I encountered, there was significant concern that design people seek to use CAD to take possession of manufacturing activities. The status of "NC Part Programming" is a case in point. The engineering course on CAD/CAM included it as the last topic and the only manufacturing technique covered. The instructor described how some 3D technologies include the ability to translate the geometric model of a product part into instructions for driving manufacturing operations, such as 'milling' or 'machining,' on computer-controlled NC (numerical control) machines. In other words, the geometric model transcribes a manufacturing activity in addition to design activities. But from a manufacturing point of view, repositioning milling and machining activities in this way renders ambiguous the identities of manufacturing people. Where before they stood at least separate from design, even if not equal to it, the stabilization of NC Part Programming, and perhaps other manufacturing activities, within CAD threatens to make them directly subordinate. One interviewee who develops and markets NC software for machining plastics expressed this concern in telling me she was resisting rewriting her software to suit the specifications of CAD vendors. She advocated a reversal in the flow of authority: "What is needed are new ways to make designs more moldable [for manufacturing purposes]."

From this latter point of view, concentrating activities at an early point in the design process through CAD/CAM technologies increases the influence of engineering designers in product development. The power of an engineering designer increases in proportion with each engineering capability added to the graphical image. As product development activities move 'upstream,' so the identity and concerns of engineering design are extended 'downstream' into other areas.

In contrast with the drawing and object orientations of 2D and 3D CAD/CAM technologies, individuals and groups involved in manufacturing seek computer assistance with a "process" orientation. That is, manufacturing people who turn to computers generally seek help in monitoring, controlling, and supporting manufacturing processes. For example, in addition to NC part programming, manufacturing engineers are interested in such topics as 'computer-aided process planning' (comparing categories of products and manufacturing operations to plan the steps for particular products), 'cost estimating' (producing lists of product parts and calculating their costs), 'production planning and control' (producing schedules for all phases of manufacturing), and 'computer-aided quality control' (managing inspection and testing of products) (Groover and Zimmer 1984: 275-461). In the small company described above, manufacturing engineers out 'in the plant' made extensive use of numerical control machinery but had little contact with design engineers and their CAD/CAM equipment.

In sum, along with the 2D and 3D technologies described above, solid modeling technologies are not positioned to fulfill the nationalist script originally defined for CAD/CAM technology. In fact, the uses for solid modeling in engineering design and manufacturing have been quite limited because solid modeling technology is unable to intersect with the identities and transcribe the activities of groups on either side. Solid modeling has been much more successful at transcribing activities in other areas not directly related to industrial productivity, e.g., animation in movie films and simulators for pilot training.

CONCLUSION

A few years ago, I heard on National Public Radio a humorous, but useful, shorthand description of America's social conservatism when it comes to modifying institutional structures. Its author was comparing the cultural justifications for law in the United States, France, Germany, and the Soviet

Union. He said that in the United States, "Everything is permitted, except what is prohibited." That sounded reasonable enough at first. In France, "Everything is permitted, even if it is prohibited," fulfilling an American stereotype of the naughty French. In Germany, "Everything is prohibited, except what is permitted," presenting the usual image of the rigid Germans. In the Soviet Union, "Everything is prohibited, even if it is permitted," calling to mind the unreasonable strictness that the Soviets had exemplified.

I was struck by the characterization of the United States: "Everything is permitted, except what is prohibited." A common image of the United States among Europeans is that it is a highly censored country. However, the censorship is not imposed by formal law or administrative fiat; it is imposed by consensus. American politics tends to involve an aggressive competition for central political space. Radical positions on either the left or the right are rejected out of hand. It would be unthinkable, for example, for a left-wing columnist or reporter to appear routinely in the national media.

As the above case study illustrates, when Americans do seek social change, they frequently pursue it in the guise of an autonomous technological development. I pointed out earlier that drawing a sharp separation between technology and society is an irony of American culture, for it grounds a social commitment to technology as the solution to social problems. Isolating technology in this way also makes it possible to view technological development one-dimensionally as inherently progressive.

The nationalist image of CAD/CAM development provides an instance of this script, but also points out its limitations. The United States has been embroiled in a national identity crisis with economic dimensions. One response has been a willingness to modify substantially the institutional separations among government, industry, and universities, but not as explicit objectives in and of themselves. Rather, the focus has been on finding technological solutions to the identity problem, a strategy that recasts institutional innovation into the need to 'adapt' institutional orientations to the technological solutions. The result has been that 'productivity tools,' such as CAD/CAM, have become visible as objects of social strategy and disagreement, while significant institutional transformations are taking place with little public discussion.

I believe an anthropology of technology can help to redirect the popular attention that is currently directed at technology and focus it back on society by systematically identifying the social judgments that empower technological developments as indeed social judgments. CAD/CAM technologies gain the agency represented in them precisely through the intensely social processes of selecting particular engineering activities, transcribing their informational content into computer code, and then injecting the resulting technologies back into those activities. To the extent that CAD/CAM technologies gain social force, the force is internal to society rather than the product of an external source of power. Technologies acquire agency, blurring the constructed boundaries between society and technology, but only through processes of social endowment. That CAD/CAM development was deflected from the nationalist script and became three different technologies endowed with the agencies of three different types of users only throws the social content of this endowment into sharper relief.

In the case of CAD/CAM, the nationalist script has played an important role in shaping the technology by legitimizing a focus on productivity. 2D drafting automation and 3D wireframe and surface modeling differ from solid modeling in that the first two look more promising to developers and users than the third as technologies for increasing the productivity of drawing and engineering design labor. But a limitation of positioning CAD/CAM as a 'productivity tool' is that such does not anticipate the diversity of identities and objectives of users who compete for resources in design and manufacturing. Not only does the overt rhetoric of productivity omit considerations of other issues and agendas, such as the selective empowerment of particular technical groups within corporations and universities, but it also absolves participants of responsibility for those issues and agendas.

In other words, since productivity is represented as a desirable national goal and since technology is represented as needed to increase local productivity, any associated problems, ambiguities, or complexities appear to be caused by the technology itself, not by any people or groups involved. Endowing CAD/CAM technologies with agency overcomes the American reluctance to modify institutional structures, but only by inhibiting participants and outsiders from considering and weighing in advance the full implications of those modifications. An anthropology of technology that critically examines technological determinism in such routine activities as CAD/CAM development can help to refocus attention on the activities of society that take place within the technology.

At present, the American predisposition toward technological determinism serves a useful purpose for activities and groups empowered by the technologies produced. The development of CAD/CAM technologies has been oriented more to the empowerment of engineering design than to the integration of design and manufacturing. In fact, seemingly as a response to this reorientation, the nationalist burden has been shifted over the past few years to the new technology of computer-integrated manufacturing, or 'CIM.' CIM developers are now relying on nationalist sources of legitimacy to justify their work on new strategies for transcribing and unifying design and manufacturing.

The students in the CAD/CAM class I observed were transformed by their new connection to CAD/CAM technologies. They not only memorized the terms and internalized the distinctions, they learned better how to integrate this connection into broader strategies to find good jobs. Although the students would probably have resisted also internalizing anthropological terms and distinctions, by assessing the agencies transcribed into CAD/CAM technologies in relation to their own identities and activities as prospective engineers, they were already practicing a rather sophisticated anthropology of technology.

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NOTES

1. I use single quotes to denote cultural categories and double quotes to denote direct quotations and analytic concepts.
2. I actually participated in this semester-long course twice. My account of the course merges the two to preserve the anonymity of both students and instructors. For a more extended treatment of identity change in learning, see Lave and Wenger (1991:52-54).
3. See Lynch (1988) for an interesting account of the "assembly-line" production of visual images in scientific research.
4. See Akrich (1992) for a parallel argument.

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