ROUTINIZING VISUAL EFFECTS: POPULATION LEVEL LEARNING IN MOTION PICTURE PRODUCTION

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ABSTRACT

Using a descriptive case method, this paper explores population level learning resulting from the introduction and development of visual effects technologies in the motion picture industry. Although the major technological shift occurred more than a decade ago, the evolution of routines for the production of visual effects continues. Based on archival data for the last four decades of motion picture production, my findings suggest that the industry has adapted its existing routines to integrate innovative visual effects technology into a variant of the traditional form of project organization. I find further evidence that some new routines have become dominant, while others have failed to survive the selection process.

1 INTRODUCTION

The motion picture effects industry is relatively new (Brosnan, 1984; Klein, 2004; Netzley, 2000). Although motion pictures have employed special and visual effects since their inception, it was only in the last quarter of the 20th century that a large population of independent firms grew up to supply effects. This growth can be attributed in part to a series of revolutions in the process technologies used to create effects. This is particularly evident in the development of digital technologies for visual effects, but there have also been process innovations in mechanical and physical effects such as animatronics and make-up. These changes have increased the complexity of production processes, the scale of the investment required to compete, and the variety of technical and artistic knowledge required to master production processes.

One result has been that in some areas of effects, the individual freelance specialist has largely been replaced by permanent firms (Swartz, 2003). As firms have become more common in effects production, the cost of effects has fallen, so that effects are used in more motion pictures than previously. The quality of effects has simultaneously improved, so that directors, producers and audiences want more of them. In motion pictures intended for global distribution the demand for effects has often led to very large effects budgets ($50 million is not unusual) and thousands of shots per project. The use of effects in minor, regional and television projects has also increased many fold.

It would be unusual if changes of this magnitude were not accompanied by significant changes in business practice and organizational form. When competitive pressure is coupled with the introduction of a new technology, there is an opportunity for new patterns

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of organization to emerge. As an industry learns a new technology, forms of organization tend to converge on an industry recipe. This sequence of experimentation and convergence is a criterion for population level learning, which Miner and Haunschild define as "systematic change in the nature and mix of routines in a population of organizations" (1995).

The research question that motivates this study is twofold. First, how has the development of digital visual effects altered the routines of visual effects production. Second, since once change that can be attributed to the development of digital effects technologies has been the emergence of effects companies, it is relevant to ask whether and how the introduction of companies into a production system traditionally dominated by individuals has altered the motion picture production system. These questions are relevant to managers of creative projects and scholars of project based organizing, for a number of reasons. The development of visual effects technologies serves as an example of how production systems can change as craft knowledge is superseded by codified, standardized industrial systems. The second question is particularly relevant to project based organizing as it addresses the question of how practitioners have resolved the problem of integrating production within supplier firms into creative projects staffed with freelance specialists. Finally, these questions are relevant because the interplay over time between effects firms and the stream of motion picture projects can give us insight into the population level learning processes associated with the introduction of a new technology into a project based industry. This example shows how population level learning goes beyond the simple diffusion of technology to alter role structure, power relations and career paths.

This study also makes a contribution by studying contemporary patterns of organizing in the motion picture industry. The co-evolution of the American motion picture industry and its technologies during its first century has been well documented (Jones, 2001; Lampel 2006; Lampel & Shamsie, 2003; Mezias & Mezias, 2000), but recent structural changes have received less attention. From the early 1970's to the present, motion pictures have been produced in a network form of governance (Jones, Hesterly & Borgatti, 1997). One of the salient features of this system is that the suppliers are nearly all individuals working as independent contractors supplying knowledge based services to projects. In this system individual specialists compete for work partly on the basis of talent, but also on the basis of social capital. Who an individual knows and has worked with, and the extent to which the individual is reputable, liked and trusted has been paramount in determining access to work (Bechky, 2005; DeFillippi & Arthur, 1998; Jones, 1996). The well defined role structure (actor, director, cinematographer, grip, gaffer and so on) facilitates specialization and is reinforced by a system of professional guilds and unions.

The injection of the effects firm into this structure has the potential to alter the way production is organized, because it depersonalizes and disaggregates important parts of the production process. While there have always been firms involved in peripheral areas, such as catering, equipment rental and film processing, the effects firm is different because it sits astride a creative process that has the potential to be competence destroying for many of the existing specializations. Make-up, art departments, locations, sets and even actors are at risk of being displaced by digital effects produced in an industrial form of organization using standardized tools and highly codified knowledge. The intrusion of firms into projects would also appear to call for the development of liaison mechanisms to ensure that the outputs of different suppliers can be efficiently combined into a coherent whole.

As a descriptive case study (Yin, 1984) this study begins with the general proposition that the technological change briefly described above should have changed routines for organizing effects production. Rather than develop specific propositions or hypotheses, my approach is to examine archival data in order to detect the kinds of changes that have occurred. Because I believe that the question is not whether population level learning occurred (Hanks, 1991), but rather what form it took and how the processes of variation, selection and retention played out, the study is exploratory, guided primarily by existing theory about the types of variation new technologies stimulate. The unit of analysis is the motion picture project as the nexus for buyer supplier relationships between visual effects specialists (including companies) and filmmakers.

Data on motion picture projects was acquired from the Internet Movie database (IMDb.com) and consists of credit data that links individuals to projects and suppliers. By examining the details of these credits, I was able to reconstruct the development of routine over a thirty five year period. The data is primarily from the U.S. motion picture industry, which facilitates the detection of patterns of change. Because the number of data points is large, even when aggregating to the project level, the criteria I use to interpret the findings are largely quantitative. For example, if certain roles change over time or if company credits or relationship structures become more common, I take that as evidence of population level learning. I begin by defining visual effects. I then describe the data and data collection method, and proceed to the an analysis of the evidence for different elements of population level learning in the production of motion picture visual effects.

2 VISUAL EFFECTS

Motion picture effects are physical, visual and audio content added to a motion picture to alter the appearance of reality. Effects are often used to simulate imaginative reality that is impractical or impossible to produce first hand, and to reproduce actual reality artificially when doing so first hand would be dangerous, impractical or prohibitively expensive. While the term 'special effects' is often used loosely to denote all effects, within the industry effects are traditionally divided into 'special effects' and 'visual effects' (Brosnan, 1984; Netzley, 2000). This study focuses primarily on visual effects, which involve manipulation of an image and are produced offline and off set. Some methods used to produce visual effects are manual animation, optical distortion, compositing (digital and optical), stop motion, and computer generated or digitally altered images and animation. Nearly all digital effects are visual. Visual effects often require an extended production period. In effects intensive projects, visual effects work begins in pre-production and is often one of the last things completed in post production. Special effects, in contrast, involve physical action, and are produced and shot in real time, on the set. Special effects include stunt work, animatronics, explosions, weather effects and prosthetics. Special effects require set-up time, but are produced on set, during the regular shooting schedule.

The development of digital visual effects technology has greatly reduced the cost of developing and manipulating images outside the camera and off the set. This is a continuation of a technological trajectory that has seen filmmakers taking progressively greater control over the production environment for the last 100 years. Soundstages, artificial lighting, sets, make-up, synchronized sound and special effects all give the

filmmaker greater control over the image produced. While visual effects such as painted mattes and optical composites have also been used for many decades, they have traditionally been expensive, slow and of limited capability. Although most studios had special and visual effects departments, there were also a number of freelance specialists in the industry.

Using computers to produce visual effects reduced cost and increased speed and quality. By the mid 1970's, individual specialists playing a lead user role (Brosnan, 1984; von Hippel, 1998) had begun to provide computer based visual effects. The technology improved rapidly in the 1980's and 90's as the cost of computing power plummeted and research on computer graphics produced numerous effects applications. Techniques and software migrated rapidly from academic settings to motion picture applications (Swartz, 2006).

The first major independent visual effects company, Industrial Light and Magic (ILM) was founded by George Lucas in 1975to provide optical visual effects for the first *Star Wars* movie. This project introduced motion control miniature photography to the industry. The computer division of the company was established in 1979, and has been a leader in digital technologies ever since. ILM was rapidly imitated by competitors in the American industry, including former employees. As digital technologies developed, imitators sprang up world wide.

3 DATA

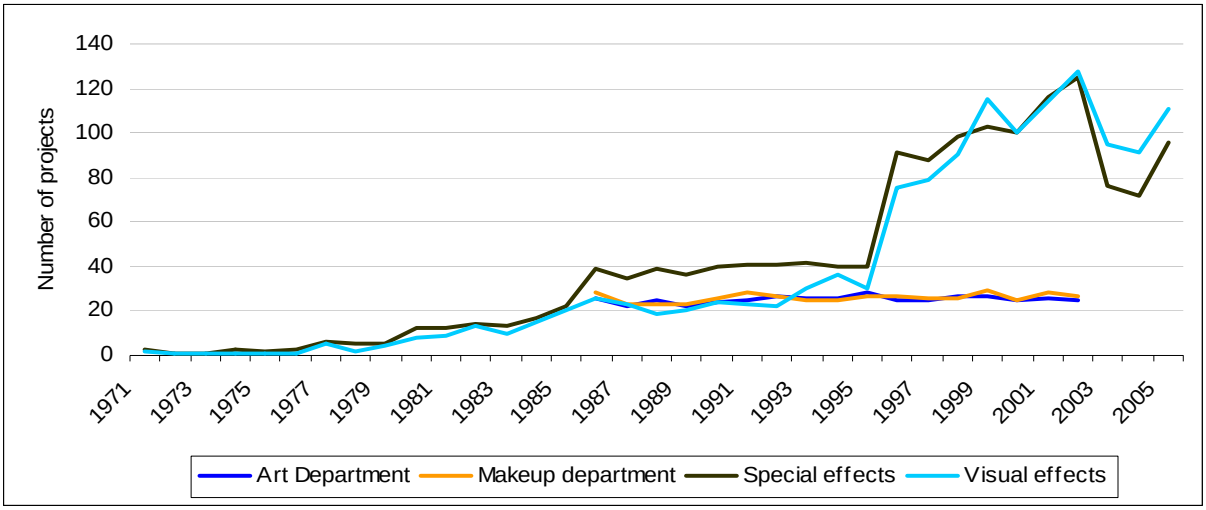
All of the data used in this study was collected from the Internet Movie Database, commonly known as IMDb.com (IMDb, 2007a; Zuckerman et al., 2003). The Internet Movie Database (IMDb) is a commercial Internet site that maintains a publicly available database of motion picture credits. Plain text files for some of the data are publicly available (IMDb, 2007b). For this study motion pictures are limited to feature films made for theatrical release. Adult films and purely animated films are excluded. To collect data for each motion picture a graduate assistant visited the complete cast and crew page on IMDb.com for each motion picture and copied the data for the four departments into a spreadsheet. The data was exported to a relational database and further manipulated to report the analyses described below. A credit record includes the name of the motion picture, its year of release, the name of the department, the name of the individual, the exact credit given (such as 'visual effects supervisor' or 'digital compositing artist') and the name of the company the person worked for, if any. Credits with no company affiliation are classified as 'Regular'.

Data collection began with a sample of 28 projects per year drawn at random from the 'movies' file (IMDb, 2007b) for the period from 1986 to 2002. My goal was to collect detailed credits data from approximately 500 motion pictures for four departments (art, makeup, special effects, and visual effects) from what I believed to be the most important time period for the development of visual effects structure. 467 motion pictures proved to have one or more of the targeted departments, but only 158 had visual effects credits. Examination of this data demonstrated that visual effects are more common in U.S. projects than for projects from other countries[†], as expected. This led to a second round of data

[†] The IMDb data includes many Chinese and Indian motion pictures, but crew and supplier data is almost universally not available for projects from these countries.

collection, for which I selected 1,132 U.S. projects released between 1996 and 2005 from the IMDb.com 'special effects companies' file (IMDb, 2007b). This process yielded data on visual and special effects departments for 1,013 projects. This data provided considerable insight into the current structures and routines of visual effects production, but the time frame proved too late to capture the developmental phases of the trajectory. To acquire data on the developmental phase of the industry trajectory, I selected all of the U.S. projects in the 'special effects companies' file released between 1971 (the earliest date in the file) and 1985. This yielded data on visual and special effects departments for 112 projects. For the years between 1985 and 1995, inclusive, I randomly selected 25 U.S. projects per year; on project from this set had no data on visual and special effects departments.

The final data set includes 1,866 projects. Because many of the projects in the initial sample did not include data on visual effects departments, and because some of the projects in later rounds had only special effects credits, the data includes 1,344 projects with visual effects data. The distribution of the data over time is shown in Figure 1. The stair step effect evident in the middle years is an artifact of the data collection process. A study of the full population of motion picture projects would show an uninterrupted increase in numbers across the period. Despite the unbalanced sample, the annual panel sizes are large enough for statistical analysis to be comparable across the range, particularly from 1985 to 2005.



3.1

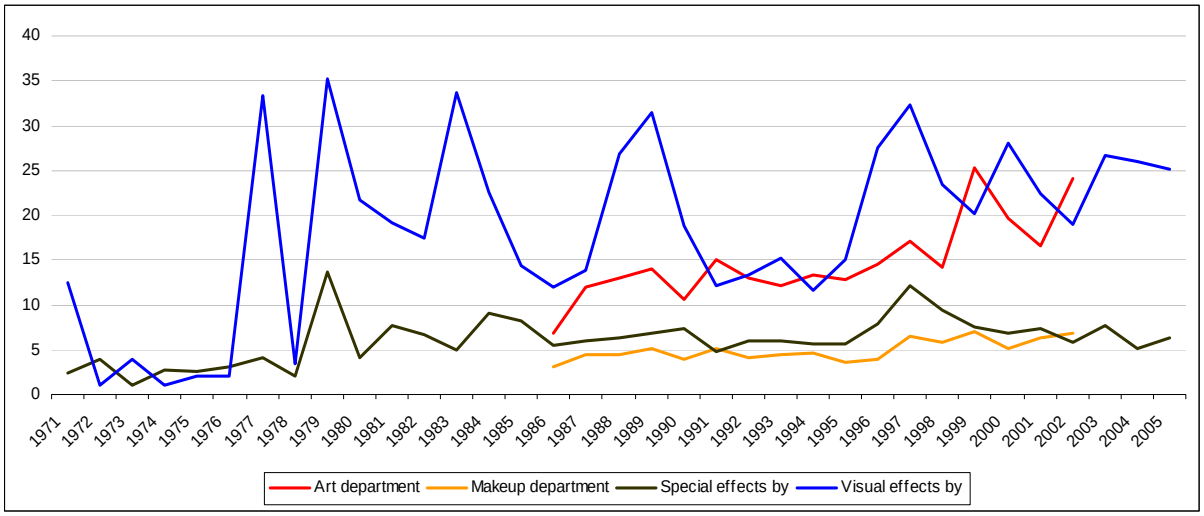
Figure 1. The number of projects departments with in the data

Additional data were drawn from the IMDb distributor and countries plain text data files (IMDb, 2007b). The distributors file supplied data on distributors for each project. The countries file supplied data on country of production for motion pictures.

4 ANALYSIS

One area where routines might be systematically altered is in the power relationships between functional areas. Because visual effects might substitute for traditional skills in art direction, set design, makeup and special effects it is instructive to see whether visual effects have displaced traditional departments or emerged as a separate function. As indicated in Figure 1, we initially collected data on four departments: art, makeup, special

effects and visual effects. Subsequent data collection focused only on the two types of effects. We examined changes in departmental headcount to see if visual effects has become a substitute for or complement to existing competencies. Figure 2, which depicts changes in average departmental headcount, indicates that art department size has grown in tandem with visual effects credits. This pattern suggests that these functions are complementary, a notion we will revisit shortly. Although it is difficult to detect, makeup department headcount also grows. What seems very clear is that while there is an upward trend in visual effects headcount late in the period, special effects headcount is static, suggesting that visual effects may be a substitute for special effects.



4.1

Figure 2: Average departmental headcount

One way to resolve the ambiguity inherent in Figure 2 is to conduct a series of multiple regression analyses, with departmental headcount as the dependent variable. Table 1 provides an overview of these analyses. The negative relationship between art department size and visual effects headcount in a multivariate model suggests that the functions of the art department and visual effects are more likely to be substitutes for each other than complements, despite the fact that both increase over time. An example of this kind of substitution would be the use of blue screen compositing techniques to substitute digital backgrounds for sets. The growth in art departments may reflect a 'sailing ship effect' response in which the old technology undergoes innovation develops in response to the new threat, or it may simply reflect a desire on the part of filmmakers to have more and better control over all aspects of production. The latter interpretation would tend to be supported by the common positive relationships between distributor status (big studios have higher status), year of release and art department and visual effects headcounts.

Special effects and visual effects headcounts appear to be complementary in the regression models. Except for differences in the kinds of motion pictures that each is associated with, if there is more of one type of effect, the other is likely to also increase. This is consistent with the 'more is better' explanation. The only systematic change in the distribution of routines evident from this analysis is that visual effects now has a place at the table, rather than being an occasional visitor, or a subordinate function of special effects or the art department.

Table1: Comparative regression results

	Art Department	Makeup department	Special effects	Visual effects
Size of art department		+	+	-
Size of makeup department	+		+	+
Special effects credits	+	+		+
Visual effects credits			+	
US ownership	+			
Multiple owner countries		+	+	+
Distributor status	+		+	+
Year	+			+
Action			+	+
Adventure			+	+
Animation		-	-	-
Crime	-			
Drama	+			
Fantasy	+			+
History				+
Horror	-	+	+	-
Mystery	+			
Science Fiction			+	+
Thriller			+	
War			+	-

4.2

Figure 3, which breaks department headcount down into regular (hired directly) and company (supplier firm affiliated) credits shows that the traditional art and makeup departments have essentially no company affiliated specialists. Special effects departments occasionally employ company suppliers, but only a few per project, and usually for very specialized types of effects such as prosthetics or weather effects.

In contrast, visual effects have been sourced from effects firms since the late 1970's. In Figure 3, the initial high regular headcount in visual effects reflects the tendency of the producers early in the current era to directly hire extensive visual effects teams. Even George Lucas in the first three *Star Wars* projects hired most visual effects talent directly, and used ILM primarily to do motion control miniatures effects. As the number of companies producing visual, and especially digital, effects increased, average company headcounts approached, but seldom exceeded average regular employment. Figure 3 validates the proposition that the organization of visual effects production is distinct from related functions in motion picture projects. In this area, the industry has clearly adopted a fundamentally new production routine.

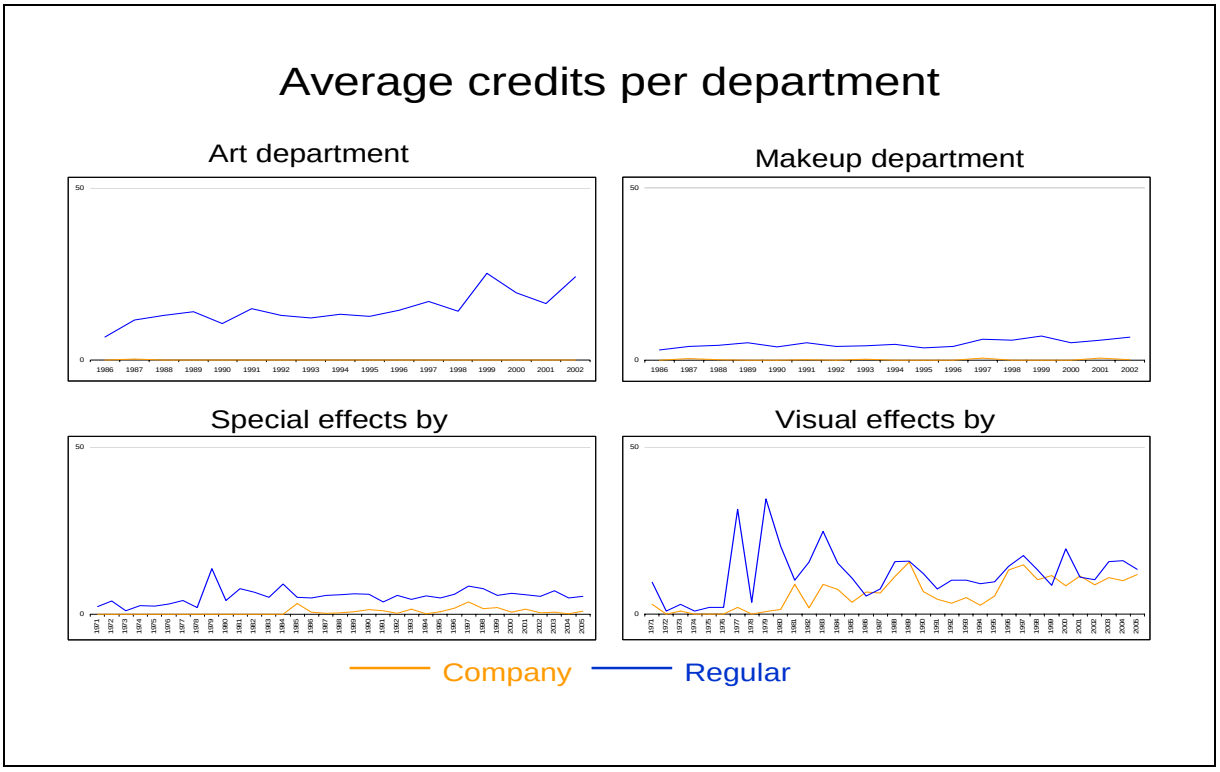


Figure 3: Company participation by department

Figure 4 shows the distribution of various supply structures among projects with visual effects credits. Three relationships are possible: the project can have only regular credits, only company credits or both. The erratic distribution in the early years of the period reflects the small number of projects per year. Beginning in about 1985, some filmmakers begin to wholly transfer visual effects production to effects companies. This structure decreases over time, so that at present it is very seldom deployed. At the same time a much larger percentage of projects organize visual effects production within the traditional project structure, using only directly hired 'regular' freelance specialists. Both of these forms peak between 1985 and 1992. The third type of supply relationship, in which regular and company credits are mixed, increases from about 1992, and is, by the end of the period, roughly as common as the 'regular only' structure. Thus, while company participation has increased in absolute terms, most supply structures retain the traditional form of freelance employment, even when effects companies are employed to do some of the work.

My interpretation of this pattern is that population level learning tried out new routines without retaining all of them. In support of this interpretation, I examined the question of whether projects with different supply structures have different types of ownership, and found that they do. Projects with only regular visual effects credits are significantly more likely to be owned by lower status distributors (independent, fly by night or regional). Projects with only company suppliers are significantly more likely to have slightly higher status owners (major television networks, regional or specialty distributors). Projects with both types of credit are significantly more likely to be owned by the major Hollywood major studios or by the specialty distributor divisions of the Big 7 global entertainment conglomerates (Epstein, 2003; Frontline, 2001). This suggests that different parts of the

population of producers have adopted different strategies with respect to the supply of visual effects.

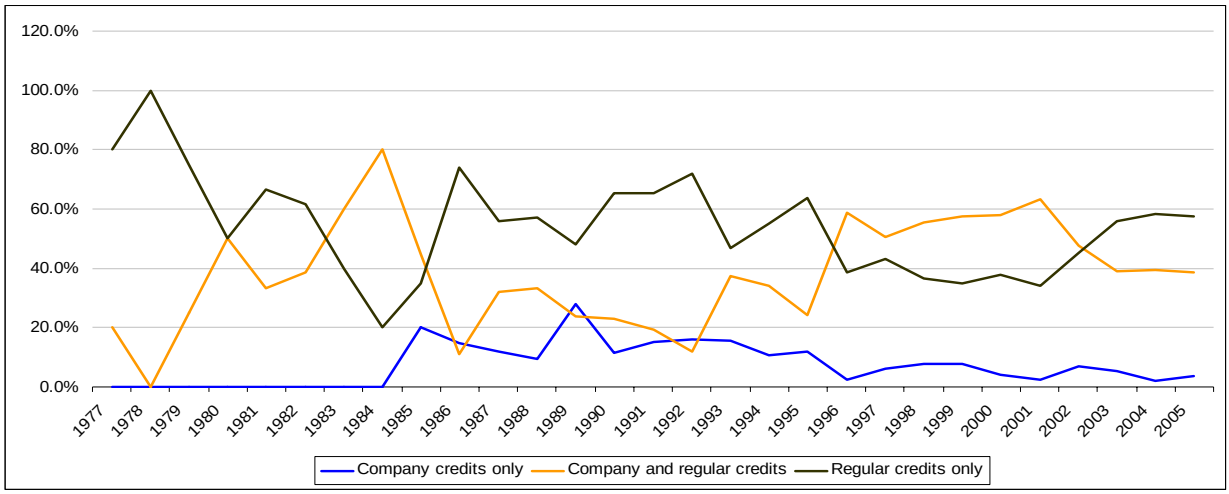


Figure 4: Distribution of visual effects supply structures

It is plausible to suggest that the 'regular only' traditional structure lends itself to an understanding of movie making as cultural production, while the introduction of organizations into the project structure pushes production toward an industrial act – which would be more consistent with an 'entertainment industry' view of cinema. While film makers have always used external organizations for some non-creative tasks (such as catering or processing film), the injection of the effects company into the creative process is a radical and perhaps unwelcome organizational response to the new technology for cultural production oriented filmmakers. The effects company, by controlling an important and costly part of the process, reduces the direct creative control film makers have over their production processes. Seen in this light, the proliferation of routines for supply relationships is perhaps a new expression of an old distinction. As such, it would appear to represent an interesting form of population level learning, since the variety of routines has increased.

A more general form of population level learning can be expected as variation in job descriptions occurs. Figure 5 shows the extent to which words are shared across credits for all four departments. Generalist job titles involve fewer words (since they don't indicate specialization) and those words tend to be more widely shared across individuals within each department. A value of .5 in Figure 5 would indicate that the average credit word is shared by half the members of a department.

In a mature function like the art department, credits are highly specialized. The inventory of words employed is large and credits are more unique, reflecting the disaggregation and specialization of work. While art department credits are highly specialized, they did not become more specialized during this period, which is as expected for a mature function. The same is true for special effects credits, which are by far the most general. The average special effects word is shared among nearly 70% of credits on the average project. This reflects the ubiquity of 'special', effects' and technician' in special effects credits. Although the trend is difficult to detect in the figure, visual effects credits became significantly more specialized over the period shown. The increase in visual effects specialization is due to the

proliferation of specialized tasks and roles, which is also reflected in the increasing size of visual effects departments. Visual effects has grown by adding skills and specializations, not by employing numerous individuals to carry out the same task. Even the most common visual effects credit 'digital compositor' never makes up more than 10% of any effects department. This pattern suggests that population level learning has occurred, as routines for organizing visual effects work continue to develop.

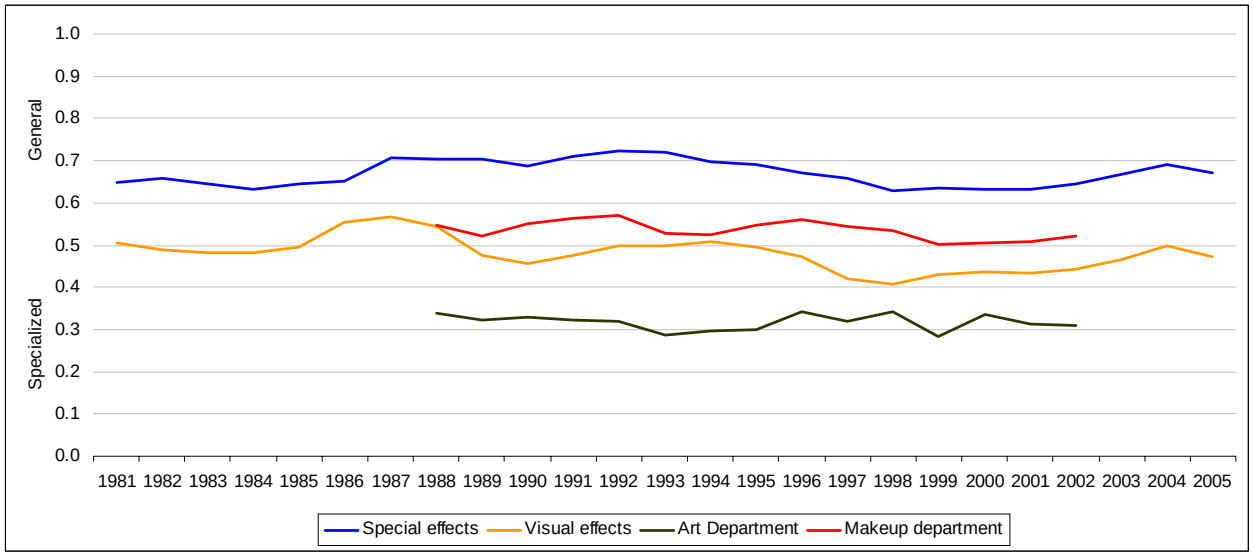


Figure 5: Percentage of credits including the average word, 3 year moving average

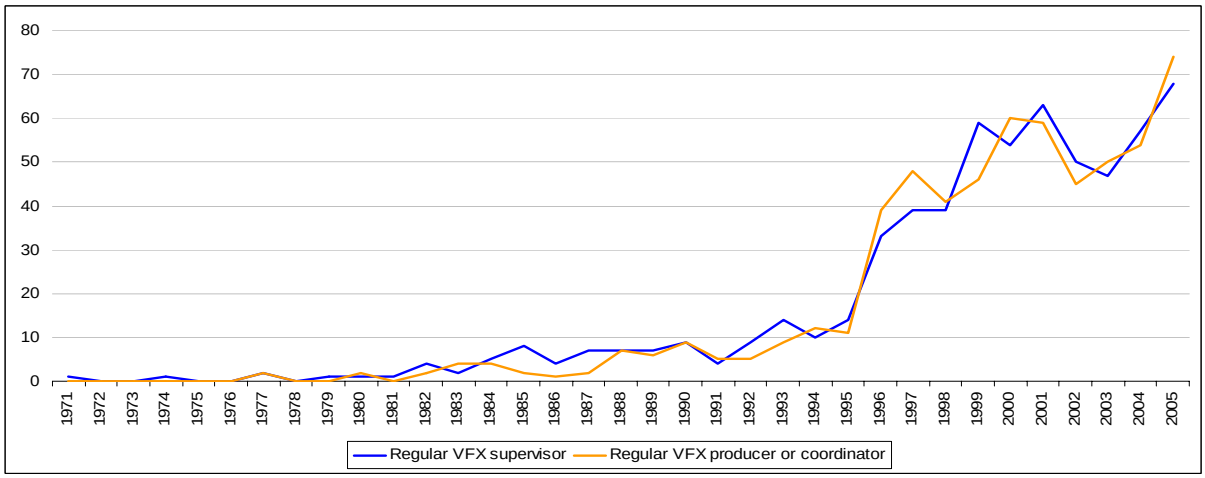


Figure 6: Visual effects supervisor credits over time

Another area for population level learning to occur is in the development of supervisory and liaison structure. The lead role or department head equivalent in visual effects production is usually the visual effects supervisor (Netzley, 2001). Variants of this role, (which as far as I can tell was first used in George Lucas' *THX 1138* in 1971), are visual effects producer (or executive producer) and visual effects coordinator. Figure 6 shows the occurrence of these roles over time. The absolute values shown reflect the distribution of data in the sample, but underlying this pattern is a real increase in the proportion of projects with supervisory and liaison roles. The routinization of hierarchy is a clear sign of population level learning.

The proportion of projects that have company credits and a specific supervisory or liaison role has increased dramatically, as shown in Figure 7. Since about 1990 this structure has been replacing one in which regular and company employees work on a project without a regular liaison role subordinate to the filmmaker. The adoption of structures that include a department head level liaison role to coordinate the work of all visual effects suppliers is clear evidence that this routine for managing effects company participation in projects has diffused widely.

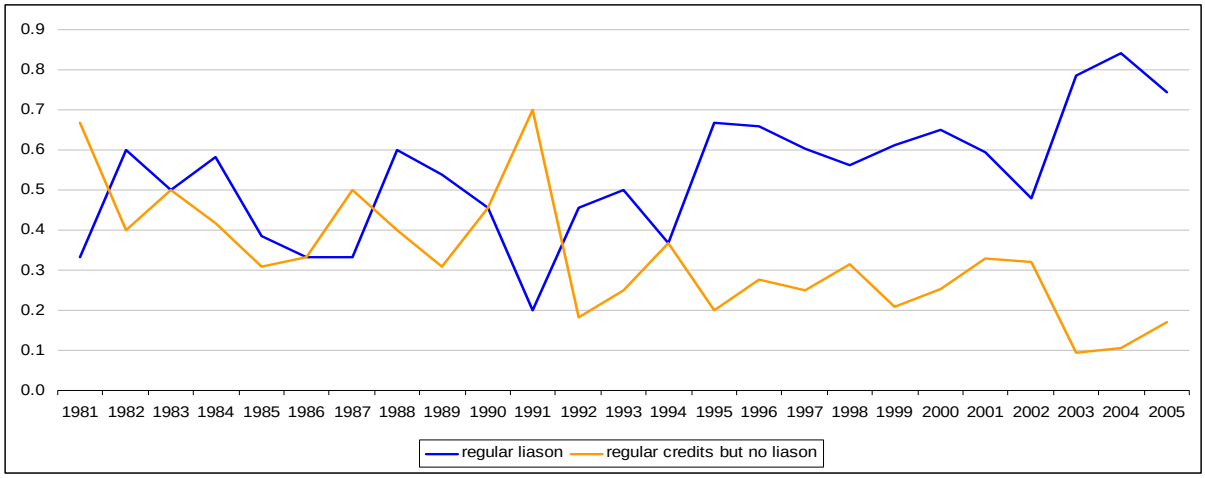


Figure 7: Liaison and supervisory roles in projects with company credits

This trend is even more pronounced when we consider what happens when a project has multiple effects company suppliers. In this case it has become the norm projects to include a hierarchy of supervisory roles to coordinate effects production. Figure 8 depicts the frequency of the various regular supervisory and liaisons roles in projects with varying numbers of effects companies as suppliers. For projects that have company credits, the proportion of projects that have multiple supervisory and liaison roles has increased dramatically. This complex structure is replacing one in which regular and company credits work on a project without a liaison or supervisory role intervening between the filmmaker and effects production. The adoption of structures that include a department head level supervisory role to coordinate the work of all visual effects suppliers is clear evidence that this routine for managing effects company participation in projects has diffused widely in the industry. So too is the elaboration of the supervisory and liaison structure reflected in the proliferation of visual effects coordinators and producers in complex projects.

In the introduction I asserted that the advent of digital technology and the introduction of effects companies into the production system had the potential to alter the routines of visual effects production. This new technology had its own nomenclature and initially, as with many innovative technologies an aura of prestige or status. This led me to question whether the new nomenclature would displace existing language as the technology diffused. To illustrate my findings, I report an analysis of the composition of 'effects supervisor' credits, shown in Figure 9. My purpose was to search for evidence that the industry had adapted its routines to the digital revolution. This analysis involved an examination of variants of 'XXX effects supervisor' for visual effects departments, where XXX can be either 'visual' or 'digital'. I found that there had been an increase in the frequency of 'digital effects supervisor' credits beginning in the late 1980's, and that this increase coincided with a decline in the frequency of the regular 'visual effects supervisor' credit. As shown in the

top chart of Figure 9, the credit 'digital effects supervisor' first entered and then retreated from use. This credit partially displaced the conventional 'visual effects supervisor' credit during the late 1990's, when the transition to digital visual effects techniques was at its height. Since that time, the conventional credit has returned to use and the digital version has fallen by the way

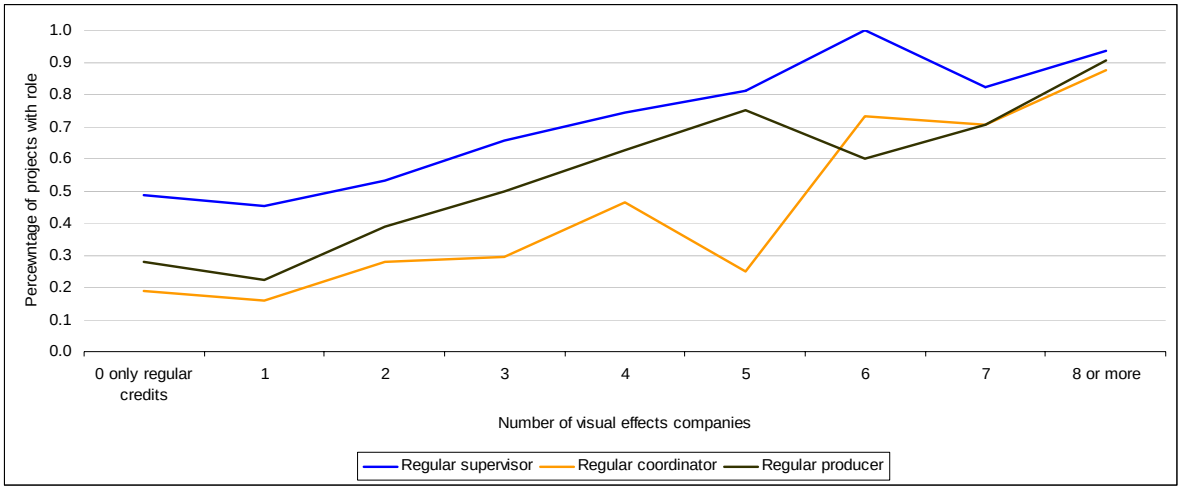


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Figure 8: Frequency of supervisory and liaison roles in multi-supplier projects

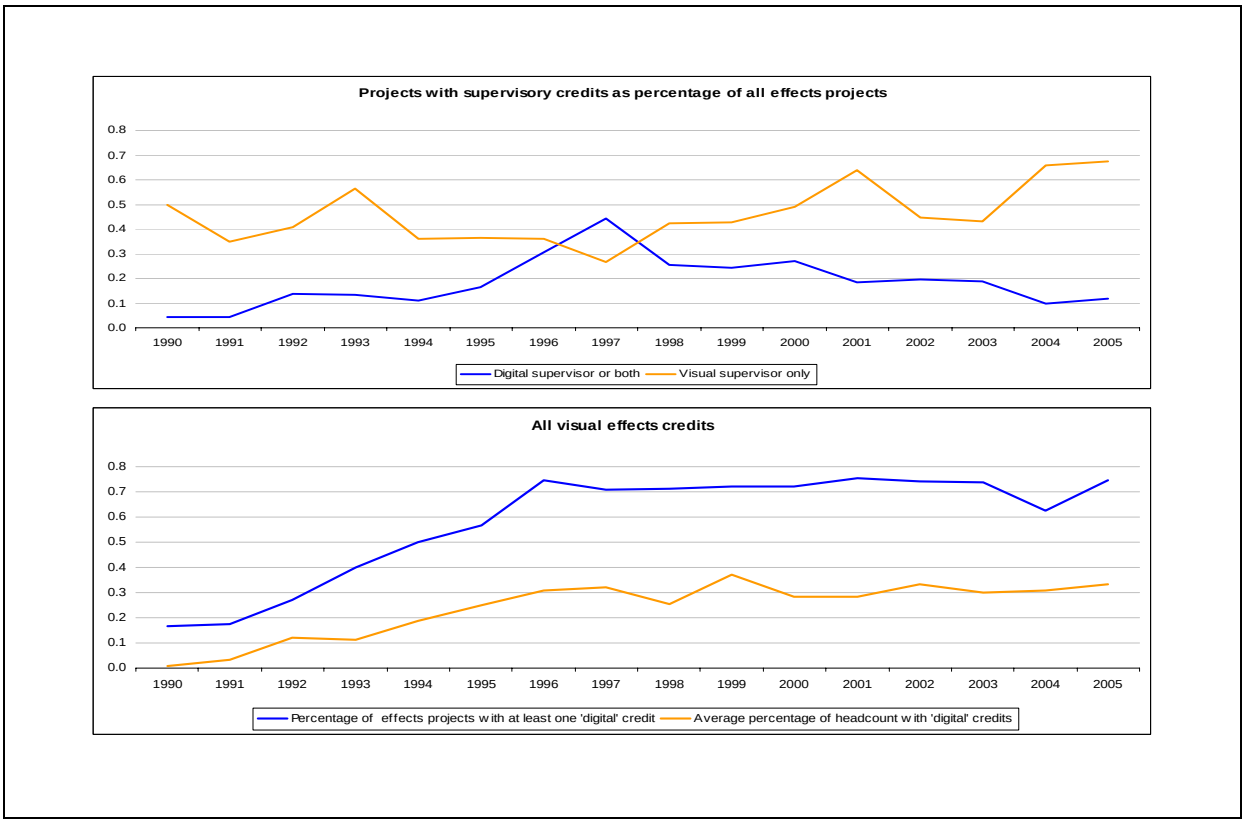

Figure 9: The occurrence of 'digital' credits.

As the lower chart indicates, this is not because digital credits are less common. On the contrary both the proportion of projects including at least one credit containing the word 'digital' and the average proportion of visual effects credits containing the word 'digital' have stabilized in the last decade. The case of digital effects credits is another example of variation occurring in visual effects routines, followed by a selection process in which the variant is selected out of the population of industry routines.

5 DISCUSSION AND CONCLUSION

As ever, the question is not whether learning occurs, but the triggers that stimulate it, the forms it takes and the processes it operates through (Hanks, 1991). This study has explored the forms and processes of population level learning in response to the introduction of an innovative technological trajectory to the motion picture industry. Visual effects, which were employed infrequently when they depended on an optical, manual technology, have become a common feature of motion picture production at all levels. This occurred as first hybrid and then purely digital technologies were developed and diffused. Television, independent films, regional or national and major studio projects have all begun to use visual effects. Although the intensity of visual effects use is higher in major films intended for global distribution, the proportion of projects using some type of visual effect has grown in all segments. This is the first indicator of population level learning: the development and retention of routines for deploying visual effects in a wide variety of motion picture projects.

I am not prepared to make a strong conclusion about changes in the relative position of the departments studied. While visual effects and the art department appear to be substitutes to some extent, both benefit from a confounding tendency for producers of major motion pictures to seek higher production values in all areas. To produce a coherent project, if visual effects are better, sets and props have to be better too. That visual and special effects are complements is an easier case to make, but this does not appear to indicate a change in routine. The two types of effects have always gone together.

In parallel with the development of advanced visual effects technologies, there has been a proliferation of visual effects firms. The data for this study captures the introduction of advanced visual effects technologies, and with it a period in which producers tried to organize effects production primarily within the traditional project structure. The emergence of the visual effects firm is a routine that sets visual effects apart from the related art, makeup and special effects departments. My interpretation of the cause for the success of this routine is that unlike other departments, visual effects quality benefits from intensive decomposition of the task. Individual specialists do specific, modular subtasks, which are relatively easily reintegrated into a complete product. This is unlike the other departments, where each individual does a relatively whole job. By providing stable employment for specialists, effects firms are better able to integrate, maintain and improve the complex processes used to generate visual effects. Effects firms are able to present producers with known capabilities and ready to go resources bases, sparing producers the difficult task of assembling complex teams of effects artists.

Despite this, filmmakers have proved unwilling to turn visual effects production entirely over to effects firms. In one of its more interesting results, this study shows that one

industry segment experimented with a company only supply structure, but that this structure has more or less died out in favor of structures that either use only free lance specialists, or a mix of individual specialists and effects firms. In this case we see increased variation during the learning process (three structures competing) and multiple routines retained as an outcome of the selection process. The association of the different structures with different types of projects appears to me to mirror the divide within motion picture production between a cultural production approach and an approach that emphasizes the industrial aspects of the entertainment industry. This conclusion is reinforced by the fact that projects with company involvement are more likely to have an intervening department head between the filmmaker and the effects production process, and also more likely to have more elaborate supply structures and supervisory structures, neither of which is consistent with an author oriented cultural production approach to filmmaking. Taken together, the relationship between company involvement and supervisory structure is evidence of the retention of a bundle of routines. This bundle includes the elevation of the visual effects supervisor role to higher status within projects, its increasing frequency, especially in projects with companies as suppliers, and the additional elaboration of hierarchy as supply relationships become more complex. As nearly as I can tell these routines have not developed in other departments.

The increasing specialization of visual effects credits is suggestive of yet another set of routines that are relatively unusual in the motion picture industry. These routines are reflected in the increasing specialization of visual effects credits, which in turn appears to be driven by the continuing evolution of visual effects technology. Although other specializations have routines for keeping up with technological developments (cinematographers attending to advances in film, lighting and lenses, for example) those routines have tended to take place within the confines of the particular craft. In visual effects, the development of technology is being driven in large part by computer scientists who work outside the industry. The types of innovation that have occurred have led to the progressive dis-integration of work into modular sub-tasks, and it is this fact that is reflected in the increasing specialization of visual effects credits.

An interesting area for future research would be to examine changes in the credit word inventory for evidence of changes in the underlying technology in use. One example of where this type of analysis could lead is given in my finding that the 'digital effects supervisor' credit enjoyed a temporary popularity, and then fell out of favor. My interpretation of this particular case of variation without retention is that the digital effects supervisor role was originally employed to manage what was then a radically new mode of production. It may also have had some element of prestige during the Internet bubble years. However, as digital production became standard, neither the prestige or the need for unique skills survived. Because the 'visual effects supervisor' credit encompasses all modes of production, it returned to its original prominence as the industry adjusted to the new technology. In some ways this is similar to Barley's story of CT scanners (1986), in which one class of participants gained momentary authority on the coat-tails of a novel technology, only to be put back in their place when the previously dominant class learned to make sense of the innovation on their own.

This descriptive case is limited to some extent by its reliance on archival data. Primary data would allow me to generate a more accurate, specific picture of individual or project level learning processes. Since my intention is to examine population level learning, however,

archival data is really the only way to get at a large number of projects over a long period of time. There are benefits to this approach. For example a primary data driven approach would not be likely to detect variation in routines based on different types of ownership simply because it would be unlikely to have access to projects operating under multiple types of ownership. Another limitation is that this study is dominated by data n the U.S. motion picture industry. The patterns detected here may not generalize to other industries, particularly industries in which something like a studio system still operates (i.e. the various Indian regional industries). Even if these patterns exist, it is not clear to me that other industries have the same approach to credits, which would make data collection nearly impossible.

I excluded adult and purely animated films from the study. Adult films seldom report detailed credits and seldom use visual effects. Animated films use some of the same technologies as visual effects in live action films, but face a greatly reduced set of coordination and integration problems. Makers of animated films can produce a set of templates and a storyboard that allow the whole production process to be outsourced to animation studios that are little more than sweatshops. That these studios are increasingly located in Korea, China and India reflects not only lower costs, but also the availability of talent that is 'good enough' for the repetitive nature of the work.

Population level learning is clearly evident in the visual effects industry. Filmmakers have developed routines that incorporate visual effects and visual effects companies into the traditional project based production system. This has occurred precisely as existing theory would predict: variation in the underlying technology leads to variation in a variety of routines, some of which are then selected and retained. That these new routines involve specialization, dis-aggregation of tasks, changes in ownership structure, liaison roles and hierarchy are what we would expect from classical organization theory. New technology does not appear to have produced new organizational forms, since the basic project based structure for motion picture production has been in place for more than a century. If anything, innovation in visual effects technology has moved motion picture production closer to the conventional corporate form of industrial organization, a move abetted by the domination of motion picture distribution by global entertainment and information conglomerates. The nature and mix of routines has changed, but the emergent bundle has very familiar features.

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