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Computer Display and Analysis of Urban Information Through Time and Space*

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Introduction

The physical environment of our cities is shaped by a complex interplay between the private sector—the real estate market—and the public sector. Private investors, in a myriad of individual decisions, attempt to maximize their economic return or simply try to find a good place to live. Ideally, public policy attempts both to respond to the needs of this private sector and also to guide it in a manner which will improve the life of all. However, public policymakers have important but limited tools at their command: the placement and nature of transportation facilities; water and sewers; the creative use of zoning and taxing authority; etc. These tools are supposed to aid and influence the private decisions and thereby improve the workings and quality of the city.

Unfortunately neither public policymakers, nor private investors, nor even students of urban life understand very well the urban market place. As a result, many private real estate decisions are incorrect and wasteful. Moreover, great public programs, such as urban renewal or the interstate highway program, have had very serious and unexpected negative side effects.

To avoid errors in future public and private decisions, one needs both a better

theoretical understanding of urban growth and a means of presenting this knowledge in a form which can be meaningful to the citizen or policymaker.

In recent years, considerable effort has been directed toward developing an understanding of the various public and private determinants of urban structure. Mathematical theories of the urban real estate market have been constructed by location theorists such as William Alonso or Lowdon Wingo. These theories have been simplified and converted into "urban growth models" which have been used to predict development in particular cities. Moreover, these mathematical models have been used extensively in the process of making decisions about the nature and placement of urban transportation facilities.

Yet, all this model-making has not been fully successful. First, it has been virtually impossible to focus on individual decision units such as households as this would greatly increase the complexity and difficulty of the analysis. Second, most of the models have concentrated on urban extension and expansion rather than renewal and change in already developed areas. Third, the analyses have tended to be cross-sectional rather than dynamic because of the difficulty of obtaining reliable time-series information and consequently they are unable to capture, reproduce, or simulate the way in which an urban area actually evolves. Fourth, the models are built to serve a definite purpose in a particular city and in many cases have not been adequately tested and evaluated in the city for which the model was prepared. And, finally, the other major reason for our lack of progress has been our inability to analyze, examine, and arrange urban data in an interactive and dynamic fashion.

The complexity of a city is great and requires the most innovative use of our data-manipulation technology. It is no wonder that our response to this problem has been more artistic than scientific. The techniques that are currently in use have done little to expand the synthesis capability of the researcher and the policymaker. There is now a ubiquitous use of statistics, and especially correlation and factor analysis, and though using these techniques is an improvement, they fail to capture either the complexity or dynamics of urban development. Indeed, these techniques are especially suited to cross-sectional analyses and in the absence of good time-series data there has been little need to apply spectral analysis in order to examine lags and hysteresis effects. On the other hand we have progressed somewhat in our graphic representation of the city, but unfortunately, these developments have limited dynamic qualities which in turn limit the opportunities for analysis. Although there are other reasons why we have made such a modest impact on coping with our urban problems, those mentioned seem to be the most important, and therefore have provided the basis for the development of this study.

The ultimate goal of our research is the construction and assessment of an urban growth model which can be used to understand alternative urban growth patterns in such a way that they may be evaluated by policymakers. In order to do this it is necessary to move forward along two paths: one which involves urban growth theory; and, the other which attempts to make optimum use of our data handling and display capabilities. In the former case the residential development of a city of manageable size (50,000) population) was selected for an in-depth study of all real estate transactions (land and total property value) and the construction and use histories of each structure. The time period examined extends from 1854 (the date of the first real estate transaction) to 1969. The object is to construct a complete history of all of the changes in these three areas so that the dynamic aspects of urban change can be analized. In addition and through time, data will be assembled on a wide variety of public and private variables which might
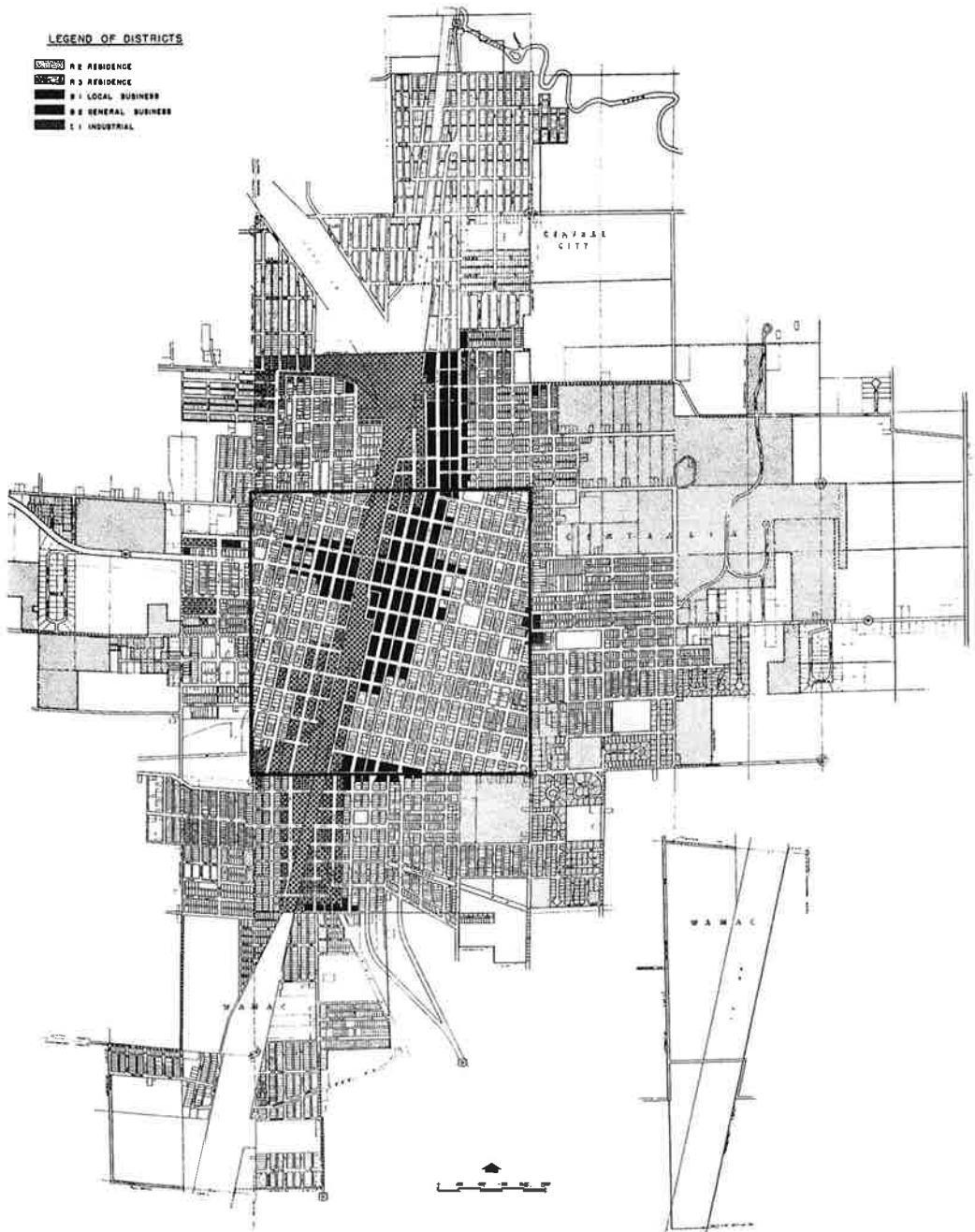
Fig. 1. Centralia, Illinois and vicinity in 1964 showing the outlines of the original town. Source: Metropolitan Planners, Inc., *Comprehensive Development Plan for Centralia*, Illinois, 1964.

have influenced the changes in these three areas. Substantively then, an effort is being made to model the physical evolution of a city with the emphasis on the residential environment.

In order to execute this analysis and exploit the data resources our other major effort is directed at improving our synthesis techniques by developing ways in which a researcher and/or policymaker may work with a computer in an interactive mode. Therefore, our intent is to design computer programs which will enable an analyst to interact with a computer using a light pen and a CRT (cathode ray tube) or using a typewriter. As a result we will be able to demonstrate and operationalize the use of computers and their calculational and display capabilities in expanding greatly one's ability to make informed choices cheaply and efficiently. The remainder of this article will describe the progress we have made in developing computer-generated display and presentation techniques of urban data.

A First Cut—The Centralia Study

Our first attempt to develop new methods of data presentation utilized information about land sales by the Illinois Central Railroad in Centralia, Illinois (see Fig. 1). The original portion of this small city (outlined area) was subdivided and developed by the railroad. One of us (JRV) had collected data about the price and land use for the first sale of all land within this original square-mile area. This very small data base – comprising about 1100 sales of raw land—could permit experimentation and innovation without excessive use of computer time.

To study these data, the analyst, sitting at the console, is first confronted by a display on the CRT which asks which display options he wishes to employ (see Figs. 2 and 3). Does he wish to study the data on a month by month or a year by year basis? He chooses
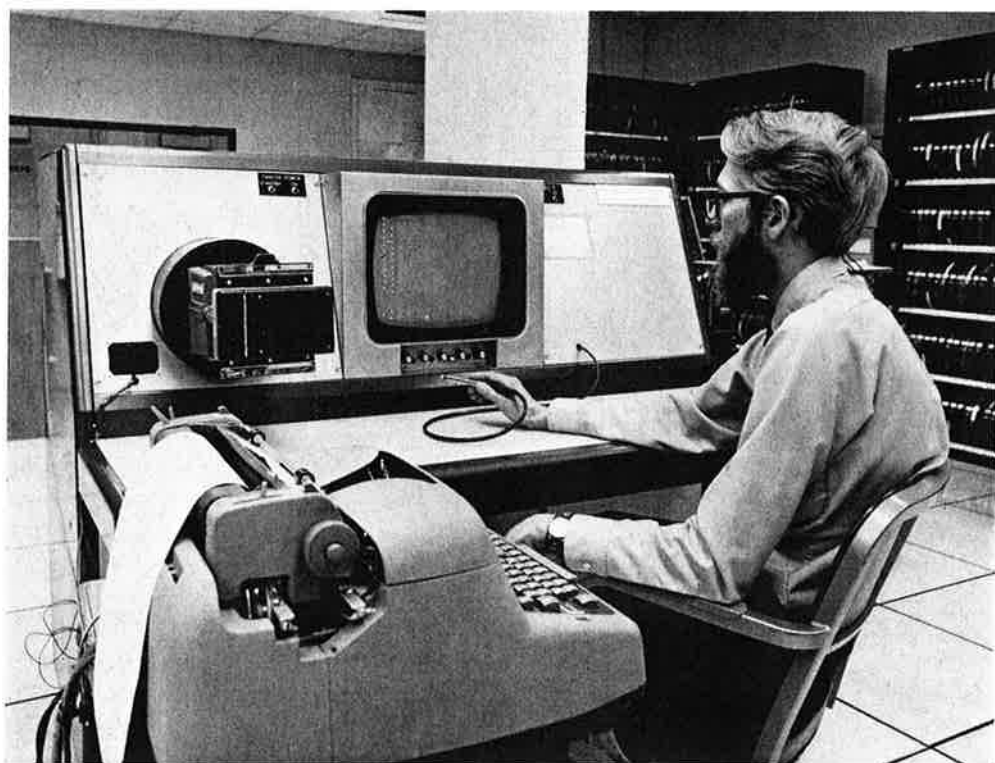
Fig. 2. The CSL display unit with operator examining display options.
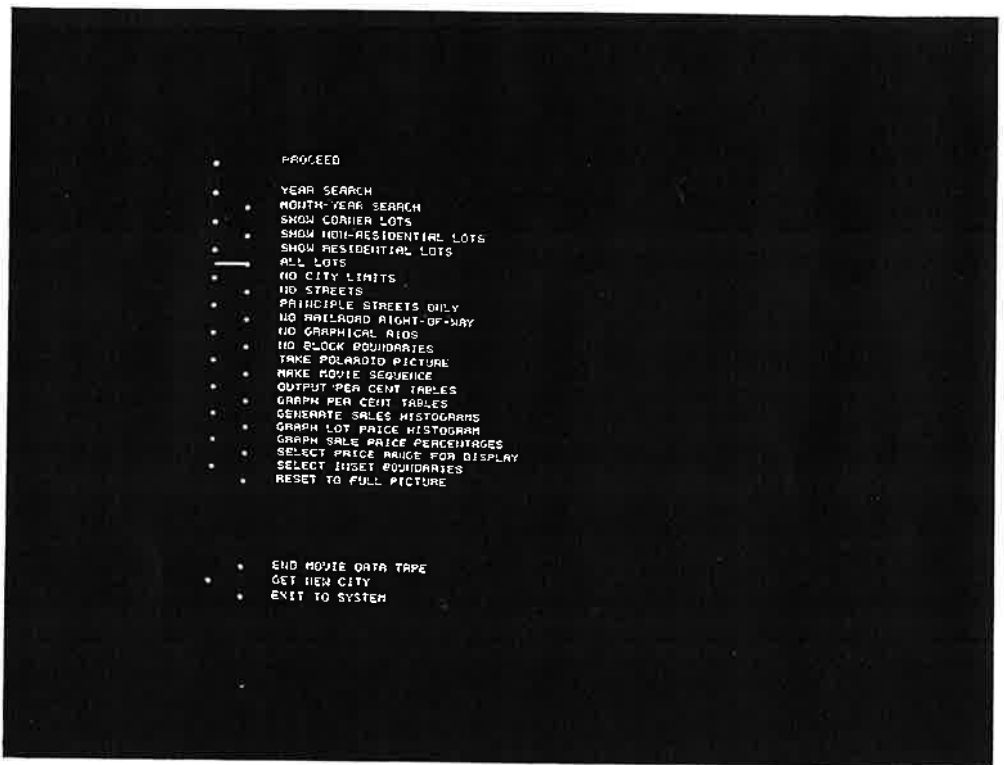
Fig. 3. The display options for the Centralia study as they appear on the face of the CRT (cathode ray tube).

Fig. 4. Operator selecting the option of viewing "all lots."

the mode he wishes by touching the CRT at the desired mode with a light pen (see Fig. 4). Another possible choice is the type of property to be seen, residential or commercial, all lots or just corner lots. Further he can study only properties within a particular price range by touching the price-range option with the light pen and then utilizing the type-writer at the display facility to insert a minimum and a maximum price per square foot. The desired price range appears on the upper edge of the display and is shown in Figs. 5, 6, 7, and 8. An inset routine was developed in order to study a limited portion of the data. After picking "inset" on the original display, a map of the community and a square appear on the CRT (see Fig. 5). Using the light pen the operator can move the square to any location and by touching "larger" or "smaller" can increase or decrease the size of the area to be examined. When "done" is touched the area within the square is presented on an expanded scale so that it fills the full scope-face (see Fig. 6).

Now, the computer begins to present data. First appears a map of the part of the community chosen for study. This map depicts the street plan laid out by the railroad at the founding of Centralia. It is held in a buffer unit in the core of the computer memory. The

Fig. 5. Operator increasing the size of the inset by touching the face of the CRT with the light pen opposite "larger."

Fig. 6. Operator advancing the date within the previously determined inset area by touching the face of the CRT with the light pen opposite 1858.

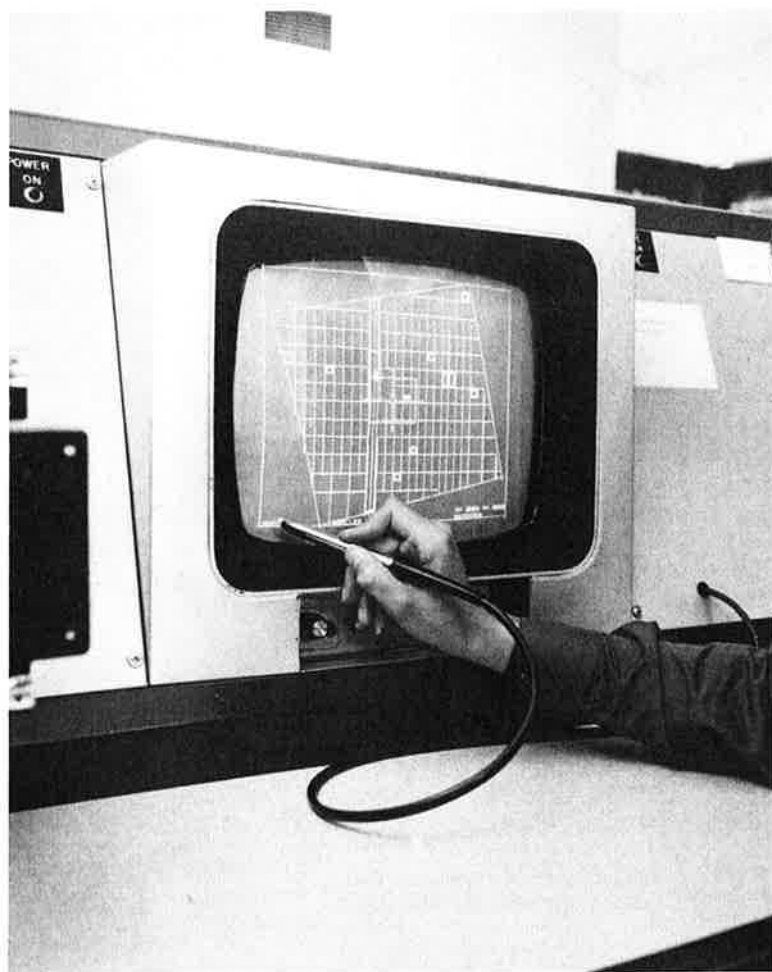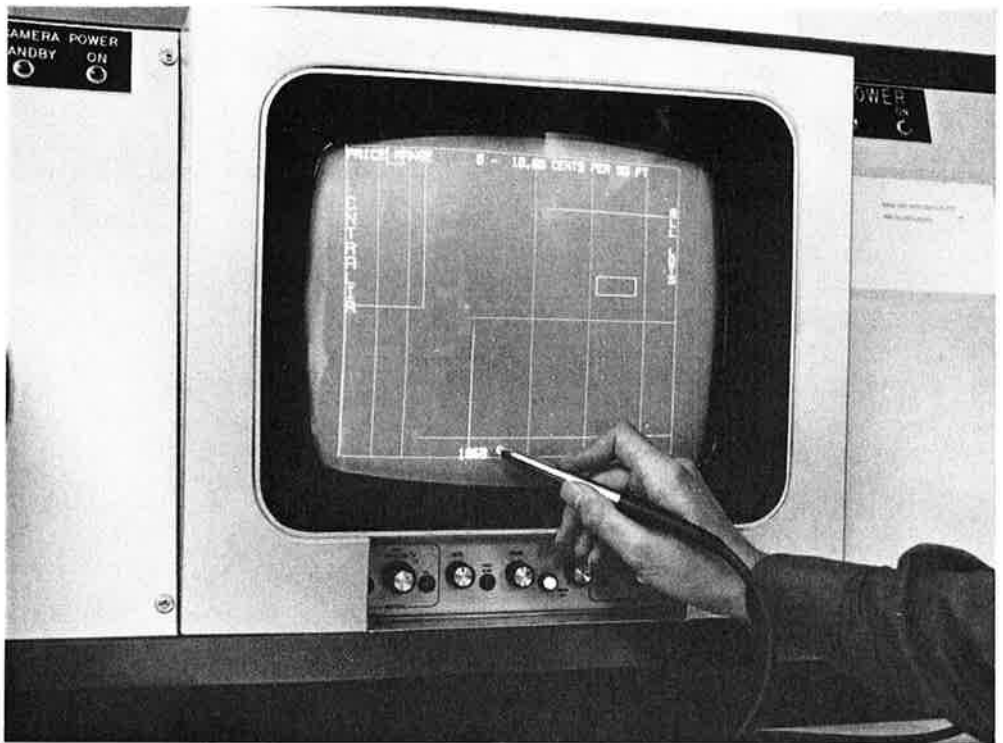screen shows the date, 1858, since year search was selected, the price range of 0–10.00 cents per square foot, and the category of "all lots." When the light pen contacts the screen the date advances and all sales in the chosen category of price and land use which occurred in the intervening period are presented as spots of light. These spots are placed in the center of the lots sold. As the light pen hits the screen again and again, the time counter advances and the additional sales are added to the picture (see Figs. 6, 7, and 8). At any point the operator can pause to record what he has learned. The photographs in Fig. 8 were made at separate points in time with a polaroid camera. Alternatively the whole sequence can be captured in a motion picture (Figs. 20 through 24).

The computer produces this time-sequence plotting by holding in core all the data records including sale price, date of sale, type of property, and x, y coordinates of property. As the data register is advanced by the light pen, the computer looks through its memory for transactions within the time interval which satisfy the criteria set by the operator when he initiated the display. All sales which meet the requirements have their x, y coordinates transferred to a buffer unit in memory. Thereafter these sales remain in the buffer and on the scope until the sequence is completed.

The displays produced in this manner can serve as a powerful tool in visualizing and analyzing patterns of urban growth. For example, Figs. 7 and 8 show the expansion in time of a diamond-shaped pattern set about a town center. The basic diamond is produced because people wanted to live at a minimum possible over-the-street distance from the center of the town. The viewer can also see an anomaly such as the arrested pattern of growth in the lower left-hand corner of the picture.

Fig. 7. Operator advancing the date for sales of all lots in Centralia by touching the surface of the CRT with the light pen opposite the displayed date. Notice the diamond shape that land sales have taken up to 1858.

The Centralia study demonstrated the feasibility of our methods and the usefulness of sequential displays for time-series studies. However, improvements in our techniques would be necessary if we were to move from the Centralia work. First of all, we sought to study a larger community with a more complex history of development. Second, we wished to include more kinds of data including all raw and developed land sales, the precise land use at each sale, and the existence of various factors which might have influenced development such as water and sewer service, transportation facilities, schools, employment, and topography. Since all these data could not be fitted into core, we needed new data-handling procedures which could transfer data from tape to core in the course of the display. Furthermore, our Centralia display program, which could add spots of light but not remove them, would clearly be inadequate for the next stage of display. Now we wished to show the whole history of an urban area and we were required to develop methods for adding and subtracting and aggregating data on the displays. A new beginning was clearly necessary.

Data Gathering for Kankakee

For the next stage, we chose Kankakee, Illinois (see Fig. 9) which is the center of a relatively small metropolitan area of 50,000, so that all relevant data could be gathered without exorbitant costs and so that we and our students would have a reasonable chance of understanding its history. However, there were other factors also influencing our selection of Kankakee. Specifically, it has, up to now, been almost entirely self-contained
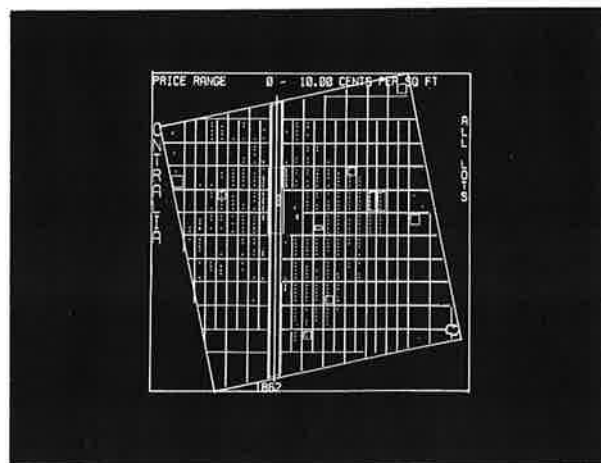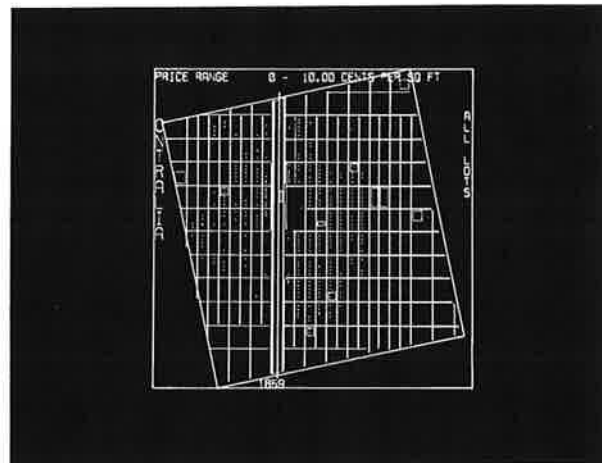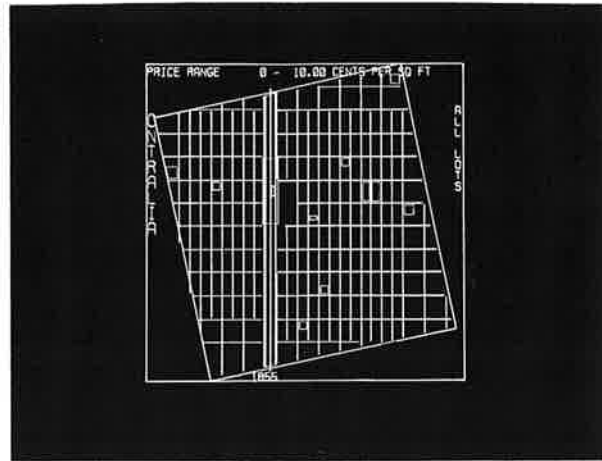
Fig. 8. A three-photo sequence showing land sales in Centralia from its origin in 1855 through 1862. The diamond pattern suggests that accessibility to the town center was an important factor influencing the time at which parcels sold.

Fig. 9. An aerial view of Kankakee in 1965, looking Northwest.

and not strongly influenced by any nearby community. It is an old town for Illinois situated on an interesting site, and has had a long and rich urban life and today possesses a diversity of income, ethnic, and racial groups. The transportation history is also quite diverse including railroads, street cars, and interurban trolleys, a complex street system, and an interstate highway. Motion through the urban area has been modified by the presence of barriers such as the river, the railroads, and the interstate highway. Finally, the new interstate highway (I-57) on the east may be expected to produce significant changes in the city in the near future because of the greatly increased accessibility to Chicago.

The job then, was to gather as much information as possible about Kankakee. We attempted to obtain sales prices for every real estate transaction since the founding of the city in 1853 for every other block in the city. These data were collected from the records in the Kankakee County Title and Trust Company and the County Recorder's office by examining sale prices and tax stamps affixed to the deeds. The history of the street and transportation system was obtained from the recorded plats of the original subdivisions (see Fig. 10) from the city's engineer, and from old maps and aerial views. These last sources are also useful in helping to suggest when homes were built or torn down and whether or not changes in land use took place. In addition we have assembled data through time on the amount and distribution of employment, family size, and the occupational status of the population. At this time we are gathering information on
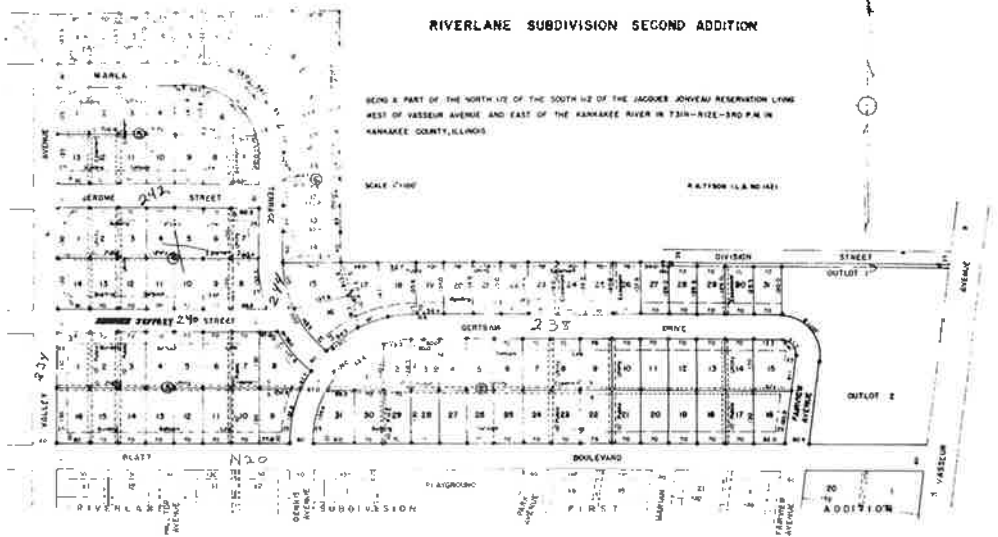
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Fig. 10. A typical subdivision plat as recorded in the Kankakee County Recorder's Office.

water, sewer, and educational services which should be in machine-readable form during the fall of 1970.

At the center of the entire data base is price information (sales price or mortgage amount) on approximately 120,000 transactions. Even the data on a single block are quite formidable. Figure 11 shows a computer printout which contains price, deed type, and date of transaction for a single block! In Fig. 12 a portion of this record is shown in readable form.

To use these data, we must determine what is being sold. By consulting maps such as Sanborn insurance maps illustrated in Fig. 13 and aerial views, it is possible to discover the history of each residential structure in the study area. Each structure is given a number (see Fig. 14) and the dates of construction and possible demolition are recorded. The number of the home sold is added to the printout or if the land is vacant, a V is inserted. These notations can be seen in Fig. 12. Finally, these data are added to the original data cards producing an inventory through time of the number of residential structures on each block, and an indication of the price history of all vacant land transactions is prepared and recorded. And finally this stage also includes the construction of an inventory which records how much land on each block is devoted to resdiential, commercial, industrial, and public uses.

The assemblage of this information will permit a detailed examination of how various factors influence dwelling unit and vacant land prices and the rate of change of dwelling unit and vacant land prices.

Presentation of Kankakee Data

In a parallel effort, a dynamic map of the town has been constructed for CRT display which presents railroads, streets, subdivision boundaries, city limits, and the river. Each of these elements is added to the map at the appropriate point in time and removed when the depicted feature changes or disappears. Figure 15 presents the growth of Kankakee in subdivision increments from June 1854 to January 1969.

Fig. 11. Complete transaction printout of block 29, subdivision #1.

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SUBDIVISION 1   BLOCK 29   LISTING OF 6/26/69
MONTH   YEAR   LOT   LOT   LOT   LOT   LOT   LOT   LOT
                   1   4   5   8   9   12   13

JUNE   1858   0 D
OCTOBER 1858
MAY   1859   100 W
DECEMBER 1859   340 W   340 W
MAY   1860   50 W
JUNE   1860
JANUARY 1861   425 W
                                                                               500 W

FEBRUARY 1861   1 W   1 W
JULY   1862   1 U   1 D
AUGUST   1864   3000 T   3000 T
NOVEMBER 1864
MARCH   1865
AUGUST   1866   350 W   350 W
FEBRUARY 1868
MARCH   1868

MAY   1868   125 W
JULY   1868

NOVEMBER 1868   600 W   600 W
MARCH   1869   10000 W 10000 W   450 W
                                                                               1000 W
JULY   1869   125 W   16
SEPTEMBER 1869   150 T

OCTOBER 1869   125 W   0 W

NOVEMBER 1869
MARCH   1870
AUGUST   1871   350 T
MARCH   1872   750 W   800 W
                                                           909   800 W

JUNE   1874   905
AUGUST   1874   300 W
                                       1050 W 905 1050 W 903
OCTOBER 1874   400 W   400 W
JANUARY 1875
APRIL   1876   200 W
MAY   1877
OCTOBER 1877
MAY   1878   905 1200 W   200 T   200 T   908
                                   1200 W

Fig. 12. A portion of the transaction printout of block 29, subdivision #1 showing typical analysis notations.

Unfortunately, we have only a small computer (see Fig. 16), a CDC 1604 which has 32K word memory that is not large enough to contain all the mapping information. To conserve core space, we hold most of the mapping data on magnetic tape arranged according to the date the feature is added. Each piece of mapping data is added to the core as it is needed in the time-sequence presentation and arranged in core according to the time it is to be removed from the map. Then when the feature disappears from the city and the data are no longer needed on the computer map, it is also automatically withdrawn from core.

As in the Centralia display, portions of the city may be examined with the aid of an inset device (see Fig. 17). In addition, particular subdivisions can be selected for special study. When the inset feature is not used, the map may be set to expand or contract automatically to fill the entire screen (see Figs. 18 and 19).

To depict the economic history, spots of light are placed within blocks which contain a specific economic feature. One can show a spot for every block which contains, for example: (a) rapid building of new homes; (b) commercial land; (c) residential over-crowding; (d) rapid deterioration of home values; or (e) sales in a given price range; as well as many other possibilities. From viewing all these displays, we expect to gain a feeling for the kinds of development which occurred in the community and as we become more experienced, our ideas can be checked against the visual image. For example, did land values go up or down in the neighborhood of the new shopping centers? Did
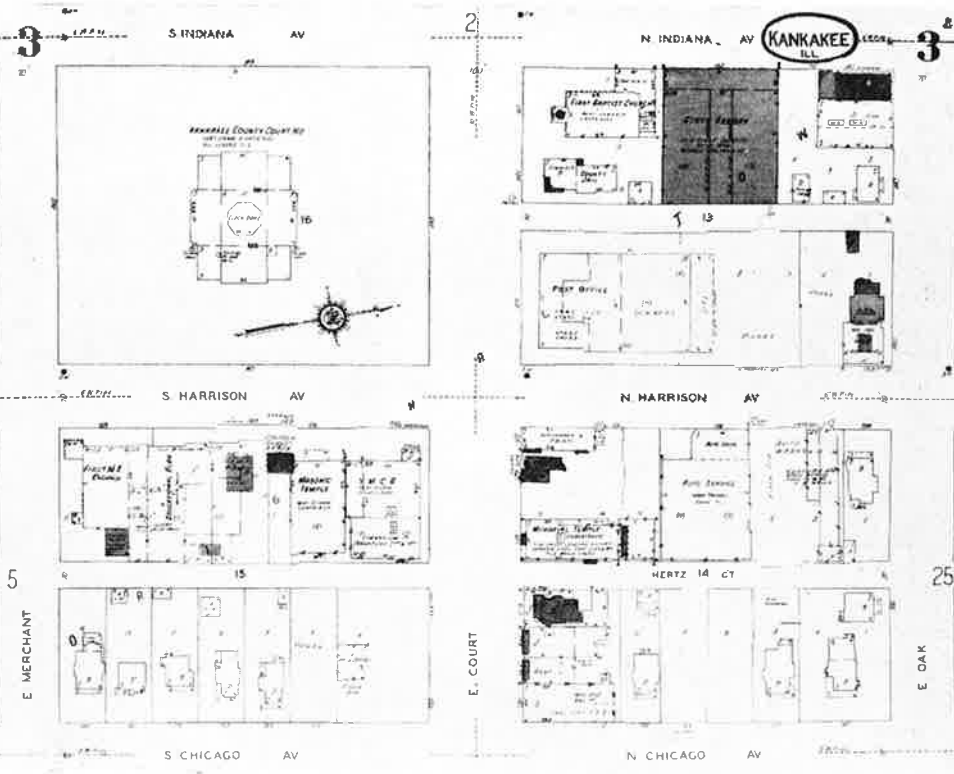
Fig. 13. A typical page from a Sanborn Map. Source: Sanborn Map Company, Pelham, New York.

velopment in the eastern part of the city precede or follow the extension of sewers? Some ideas may require new programming: for example, to show a spot of light for every block which has both deteriorating home values and new commercial land uses in the neighborhood. In this way, our computer program and our understanding of the community will grow together.

There are three problems which make the data-handling and presentation task for Kankakee very different from the one for Centralia. First, we have very many different kinds of data for Kankakee; land use, structure inventory, price information, streets, schools, etc. Second, we have much more data. It will obviously not fit into memory. Third, we cannot predict before we begin to know what kinds of relationships we shall see and wish to explore.

To overcome the core-storage problem, we must hold data on magnetic tape, feed it into core as it is needed in presentation, and free the storage space as it is no longer needed. As with the map, the best way to arrange for this reading, use, and elimination is to arrange our data sequentially in time on the tape and in the sequence they are to be eliminated within core.

In order to study the large variety of relationships which will arise in our problem, it is quite necessary that the tape records be both flexible and compact. For different types of studies, tapes are required which contain various combinations of the different types of data. It is undesirable to have blank spaces and unnecessary data on the tapes because they will slow down the presentation and take too long to read. Therefore, we have

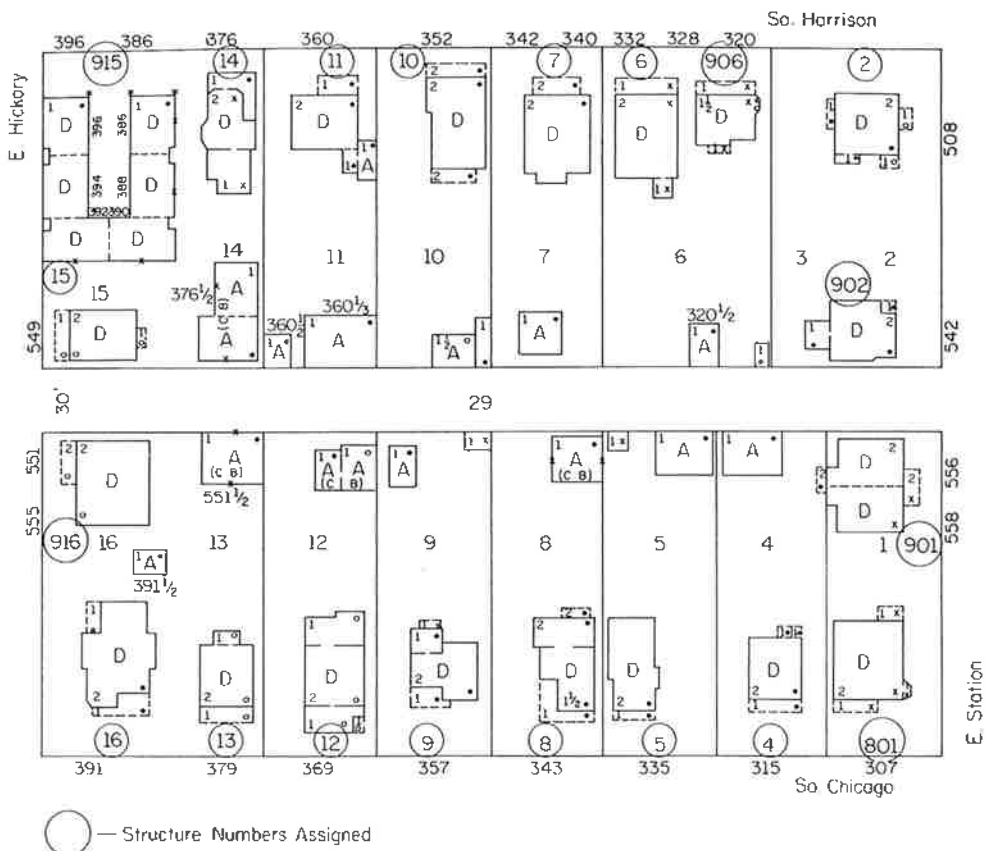Technological Forecasting and Social Change 2 (1970), 77–103   Leo P. Kadanoff et al.

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Fig. 14. A typical block in Kankakee with structures numbered for analysis.

constructed programs to permit a variable data format. By using relatively simple instructions, a bit analogous to Fortran, the programmer can select, recombine, read, and write data records which contain different data of variable length and composition. Thus, after a few minutes of programming time and a few more minutes on the computer, the programmer could make up a tape containing, for instance, only the price per square foot for sales of vacant land with date and location, together with the number of residences per acre or block at the time of sale, and a notation to indicate whether there were industrial land uses on the block. Then we could see for example whether industries on overcrowded blocks increase or decrease the price of vacant land. This production of a variable data format and its associated read, write, sort, and merge routines is a complex programming problem. However, a result of the effort expended in this direction is a flexible and quick data-handling facility.

Using these data-handling methods we have the potential for flexible and fast visual presentation of the Kankakee data. The expected result of this visual study is an appreciation of the variables which determine and limit urban growth. Following this stage of our analysis we will then attempt to develop mathematical relationships or "models" which might provide a numerical explanation of that which we have seen. For example, the predicted quantities might be prices for homes and vacant land as well as the extent of residential development. These variables or their rates of change in time might be
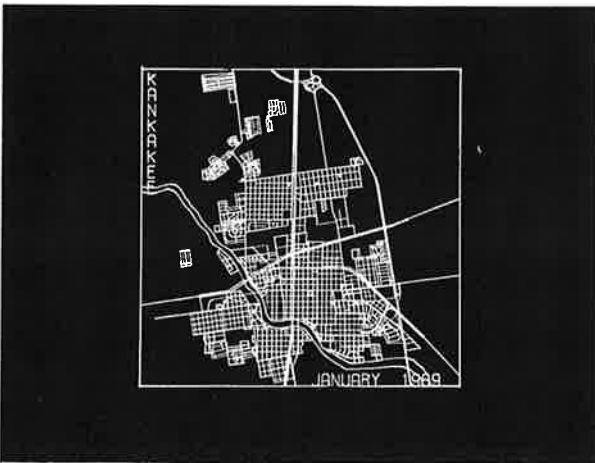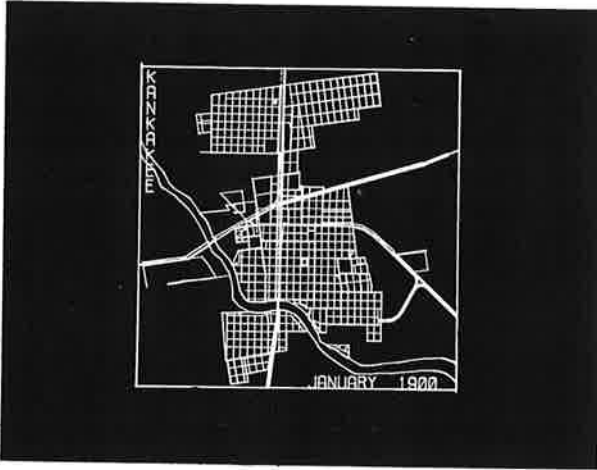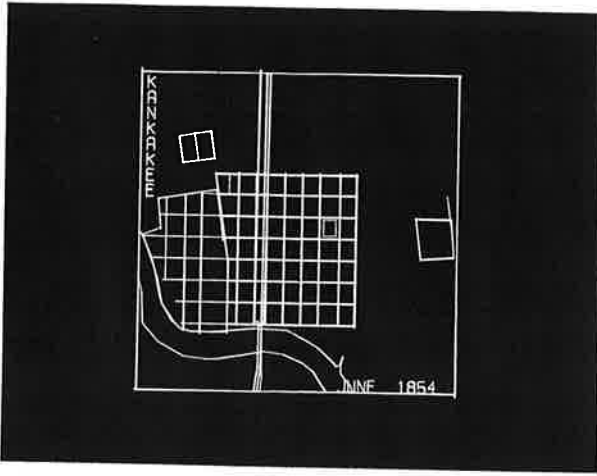
chnological Forecasting and Social Change 2 (1970), 77 103   Leo P. Kadanoff et al.

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Fig. 16. The computer room of the Coordinated Science Laboratory showing the display unit on the left, tape banks, console, printer, and computer in the far corner.
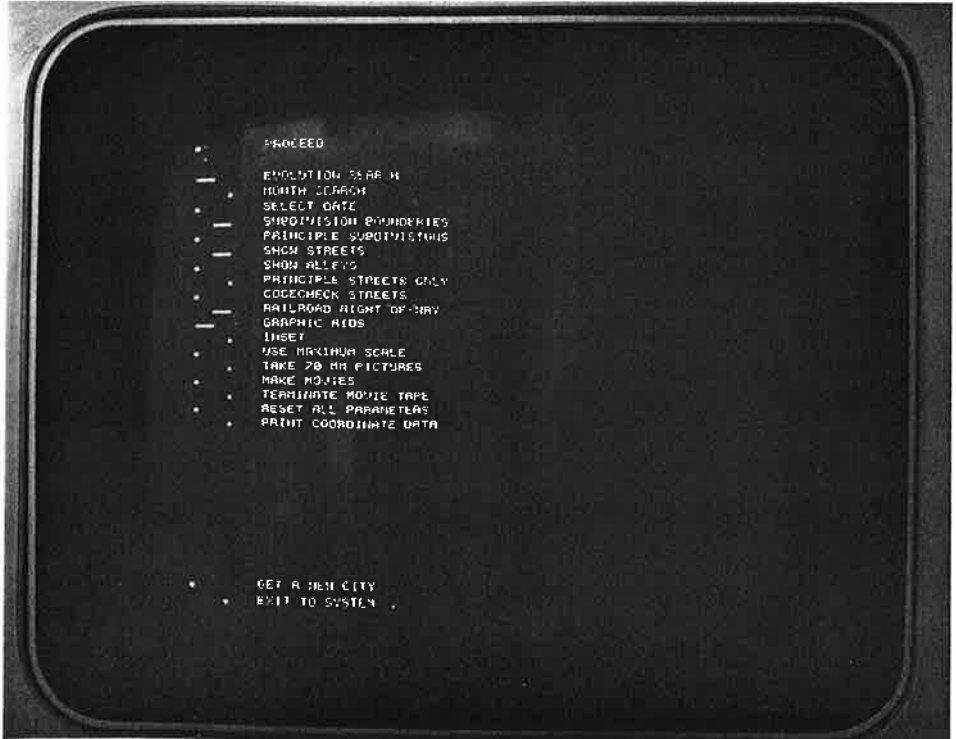

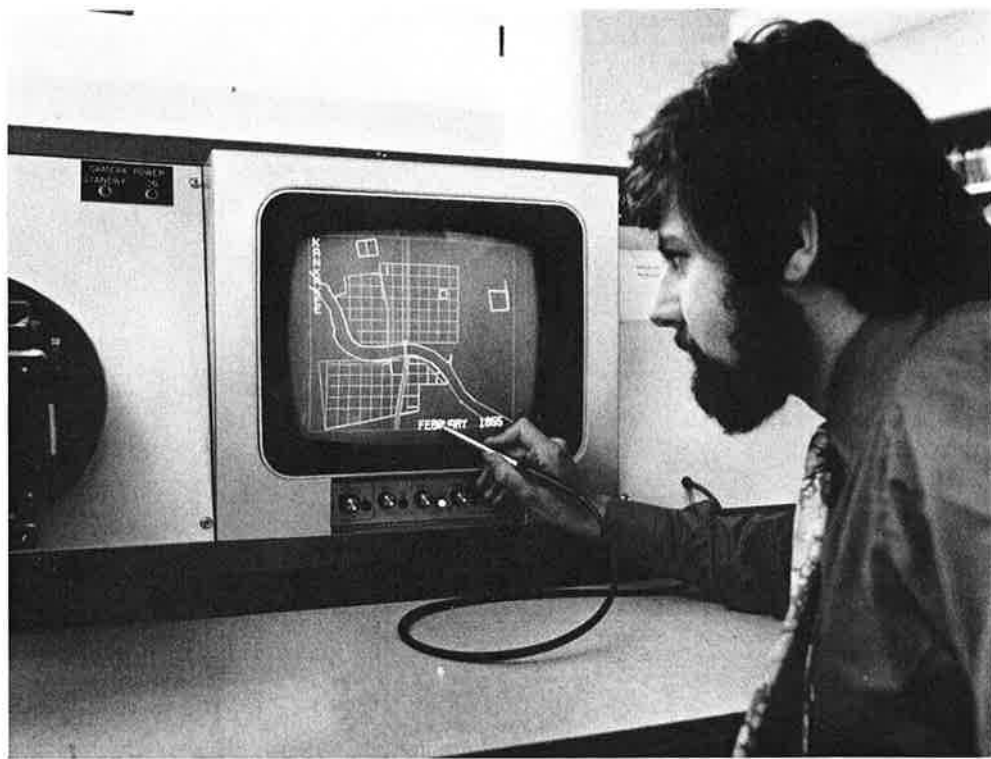Fig. 17. Kankakee options as they appear on the screen of the CRT.

Fig. 18. An operator examining early subdivision development in Kankakee.

predictable in terms of causative variables such as prices in the immediate neighborhood, time-to-travel to the center of town, quality of schools, presence of sewers, topographic features. This effort then seeks to predict the cities' growth.

While the model is being constructed and tested, the display facility would still be in use. Using a spot of light the computer could show a particular sale or block which disagreed with the model's predictions. With such a visual display of errors, we would have a guide to the correction and improvement of our mathematical relations.

In the end, we would have a model which would have a known reliability in the context of Kankakee. We would also have a considerable understanding of which variables proved significant in determining the growth through time of this community. At that point, it would be appropriate to see whether the knowledge gained in the Kankakee study could be extended and applied to other communities. Hopefully, our deeper understanding of the significance of the different variables which enter the problem could make our analysis of another city more speedy and less complex.

A Hypothetical Example: The Location of a Regional Expressway

As mentioned at the beginning of this article, the ultimate objective of our study is to provide a decisionmaker with the means, both substantive and methodological, to improve his ability to make a choice among alternatives. An example of what such an improvement might be like was developed in a movie prepared by the Coordinated Science Laboratory in conjunction with the Ford Motor Company which depicts the regional development consequences of alternative locations for an expressway. The movie was
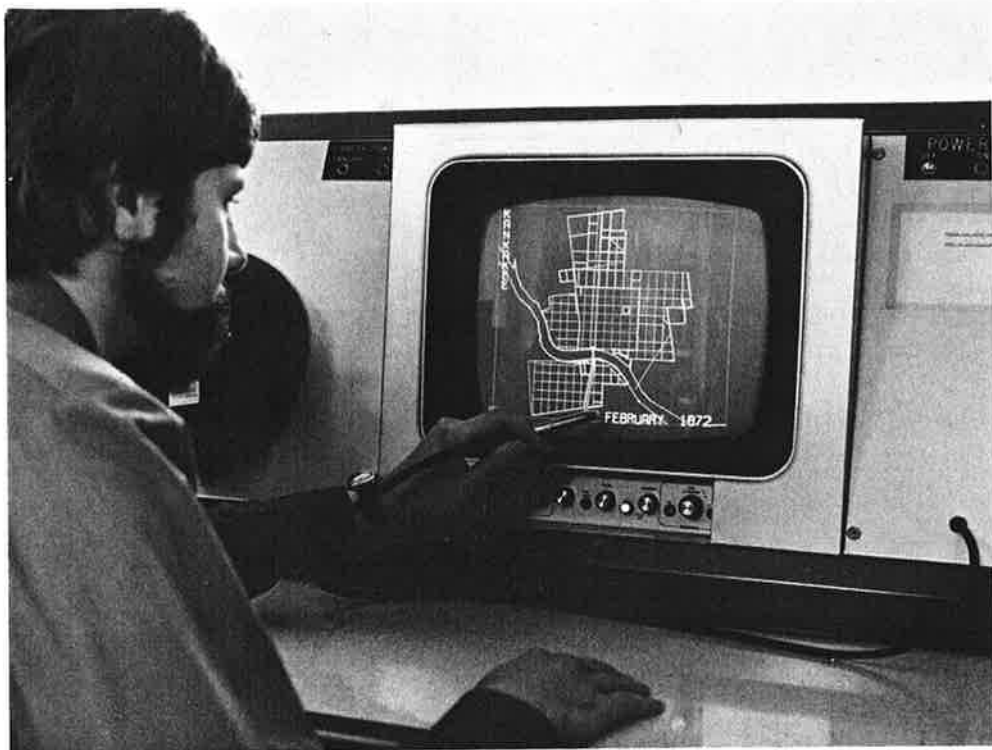
Fig. 19. An operator examining subdivision growth of Kankakee up to February, 1872. The display always fills the screen as new subdivisions are added or older ones subtracted when time is advanced by touching the light pen to the face of the CRT opposite the date.

designed to portray how a policymaker might solve a problem using on-line computer graphics in an interactive mode. Consequently, the demonstration simulates both a regional growth model and the way in which an analyst would interact with the computer using a light pen or a typewriter.

Our example assumed two major conditions:

(a) that there is a reliable regional growth model which will spatially predict and distribute population as a function of changes in accessibility; and

(b) that computer graphics techniques exist which will permit an analyst to input information into the model by drawing with a light pen on the face of the CRT.

Further we constructed the following hypothetical situation:

(a) a region with a relatively level surface containing a distribution of varying sized urban places linked together by state and country roads and an interregional railroad passing through the major urban centers;

(b) some arbitrarily located city boundaries;

(c) that the state highway department intends to construct an interstate highway through the region, and that there are two possible locations for the facility; and, finally,

(d) that the ultimate choice of the highway planners depends exclusively on the criterion of how the new expressway will influence the spatial distribution of the population in the region.
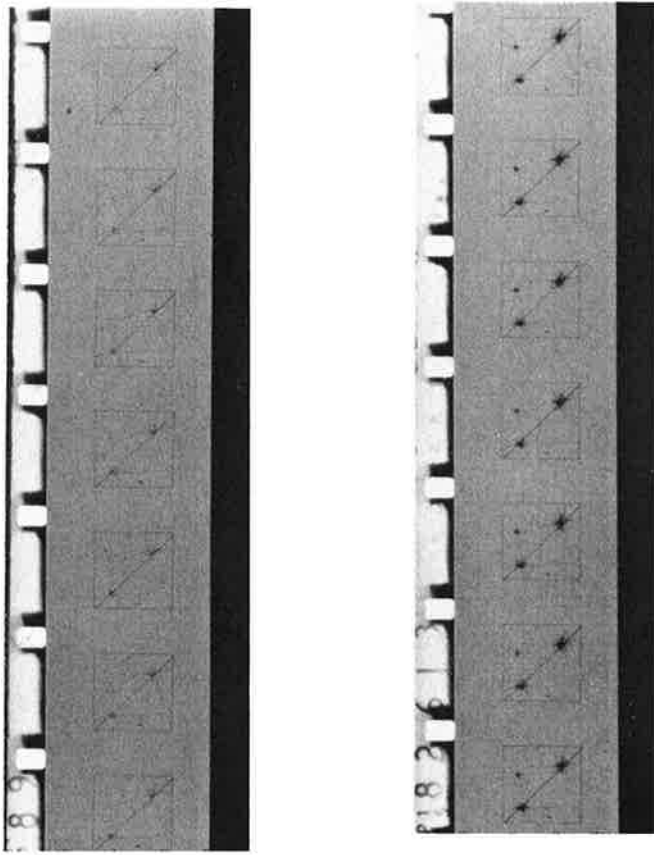
Fig. 20. A film strip from the Ford movie showing the region and its growth assuming that an expressway is not constructed.

The problem, then, is where should the facility be located. The existing structure and development of the region is shown in Fig. 20, with each spot of light corresponding to a quantity of population. To this the computer adds and distributes spots of light (population (corresponding to the amount of growth that takes place each year. The growth period extends from 1950 to 2001. Our assumed regional growth model distributes spots of light or new growth using a random number of generator with development density decreasing exponentially with increases in distance from urban centers. From time to time, new industries have been arbitrarily added to and distributed in the region, and are represented by the symbol I. In addition, city boundaries have been enlarged to encompass new growth around urban centers. These changes were also arbitrarily decided upon. Taken together, our hypothetical model is obviously and at best a very crude simulation of an actual regional development pattern. Nevertheless, it is adequate enough to permit the computer to display on the CRT what a regional growth pattern might look like at different times in the future.

Figure 20 shows changes and growth in the region assuming that an expressway is not built. The operator, then, in Figs. 21 and 22 simulates drawing on the face of the CRT the location of the two alternative expressways and Figs. 23 and 24 present the development
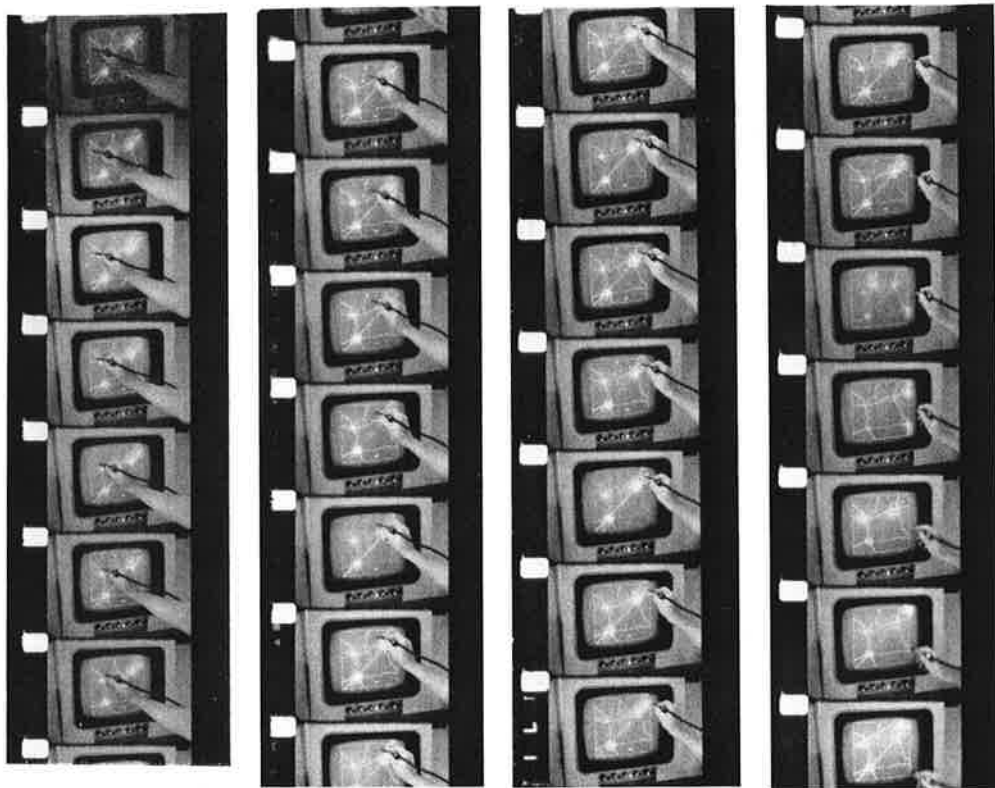
Fig. 21. A film strip from the Ford movie showing an operator simulating the drawing of the expressway through the northern portion of the region. The operator simulates drawing the location of the expressway from left to right and the bottom frames show the computer drive display of the located road.

consequences associated with each possibility. Figures 25 and 26 are enlargements of selected years from the film sequences. The operator is now able to view and analyze the various development patterns and presumably reach a decision as to which is most satisfactory.

This hypothetical example illustrates how an analyst or a planner could interact with a computer to explore a number of locational alternatives. Although a region was used for the simulation, the principles could be applied to an urban area. Consider a planner in Kankakee trying to decide simultaneously the consequences of locating a new school, extending sewer lines, improving some city streets, building a bypass expressway to the west, renewal of a deteriorated area, and building a new shopping center on the east. These elements as well as others could be input into the existing structure of the city using a light pen or a typewriter and then using a calibrated growth model the computer could quickly present what the city would look like as it evolved through time. Obviously, the nature of the problem could be, and probably would be, much more complex if one introduced such things as changes in interest rates or sequential capital improvement programs. Nevertheless, if a powerful theory is available, the analyst could examine a wide range of differently structured alternatives and with this knowledge our chances of designing an improved living environment would be greatly increased.
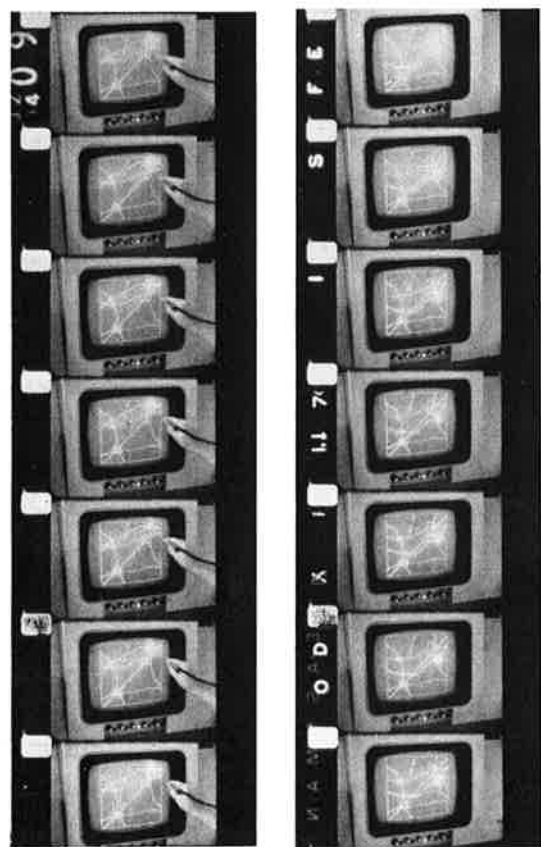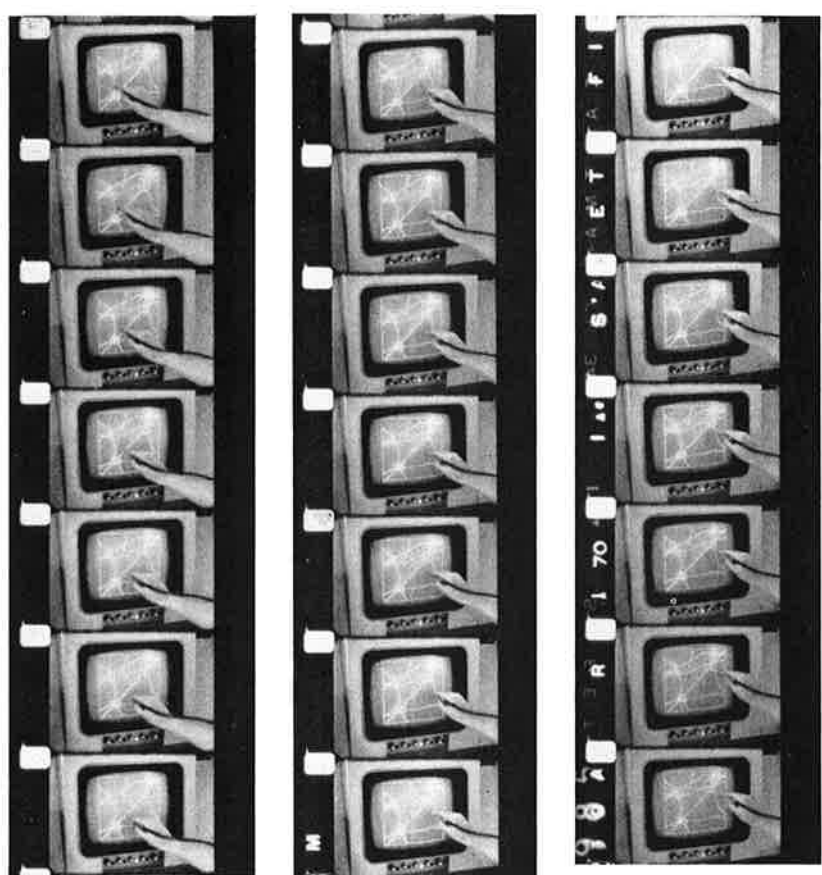
Fig. 22. A film strip from the Ford movie showing an operator simulating the drawing of the expressway through the southern portion of the region. The operator simulates drawing the desired location of the expressway, and the bottom frames show the location of the road.
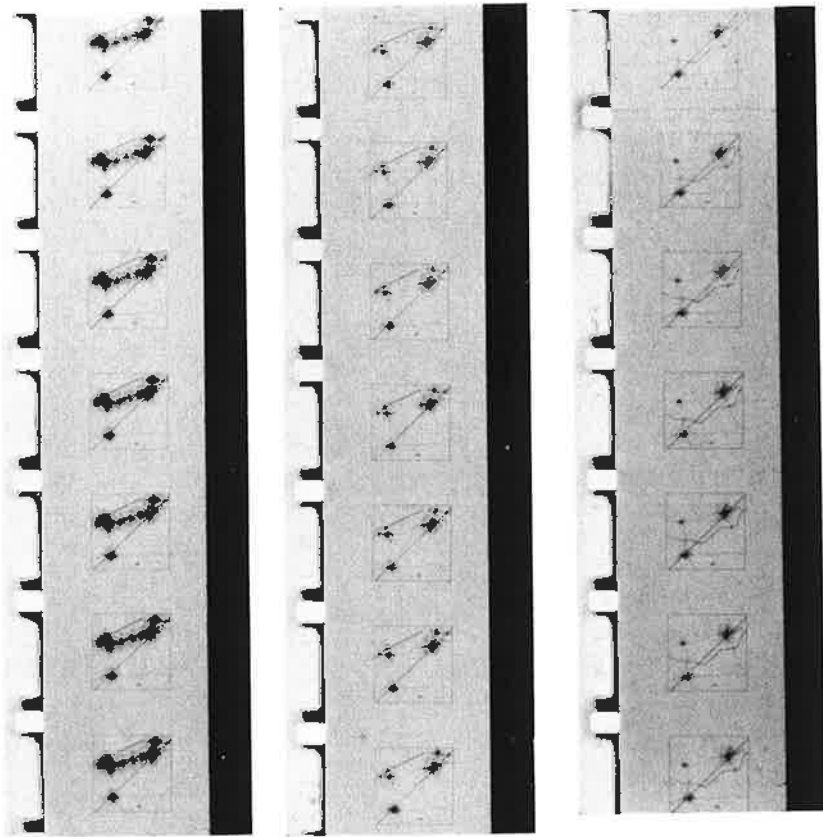
Fig. 23. A film strip from the Ford movie depicting the anticipated population distribution assuming that the northern alternative is constructed.
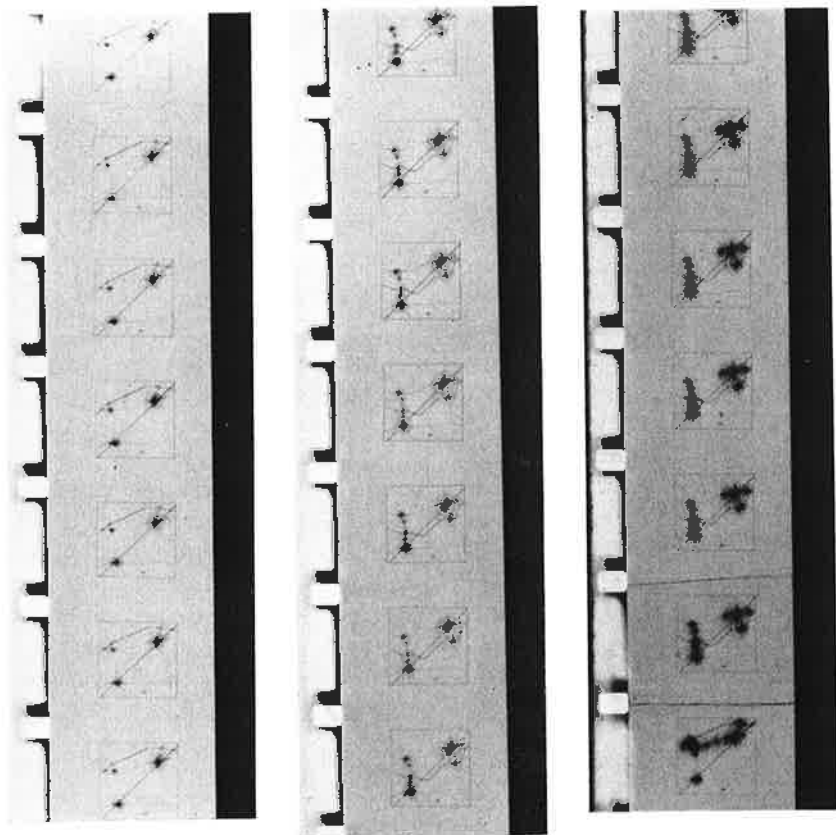

Fig. 24. A film strip from the Ford movie depicting the anticipated population distribution assuming that the southern alternative is constructed.
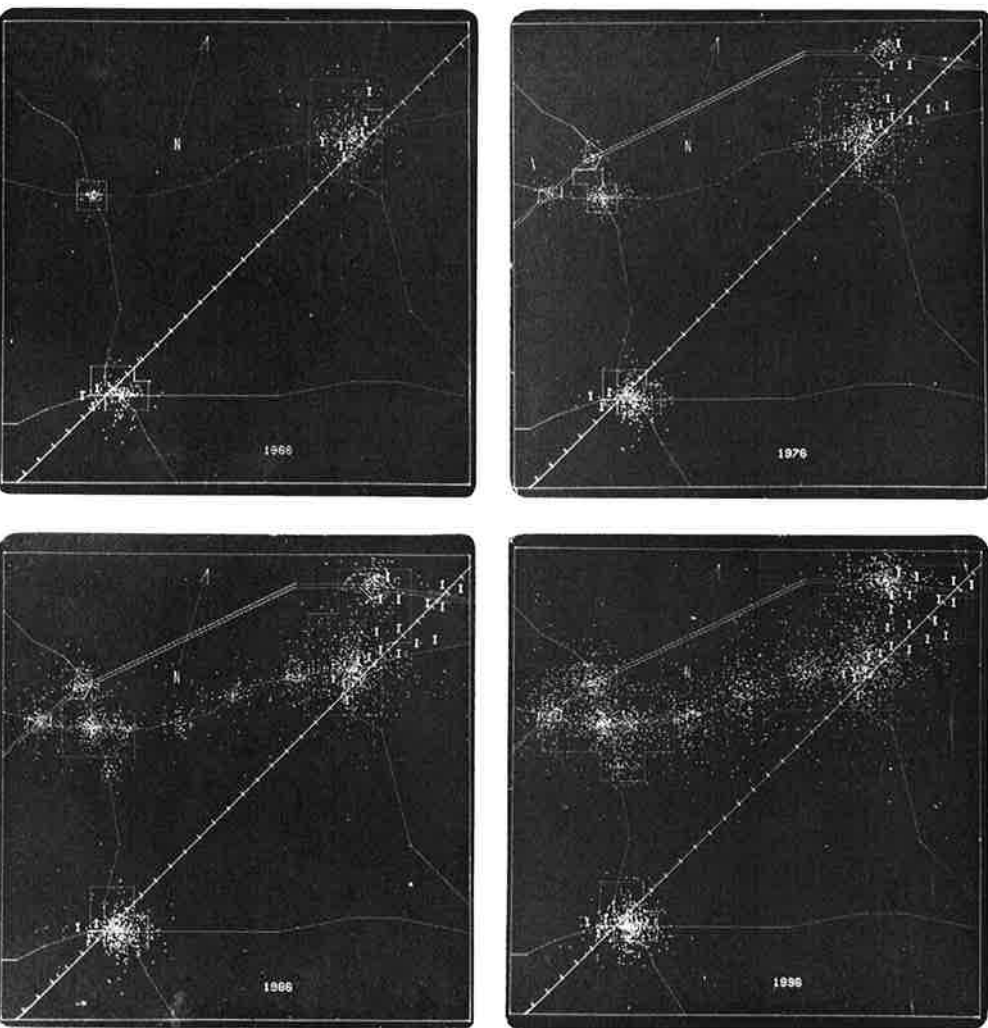
Fig. 25. Enlargement of selected years for Northern alternative.

A Technical Note on the Display System

The display system (see Fig. 2) used in this project was designed and built at the Coordinated Science Laboratory in order to explore the graphic representation of a wide variety of computer-generated data. The major objectives guiding its construction were that the system should be flexible, easy to program and operate, and require a minimum of computer memory space. At the time the display system was constructed it possessed a number of unique qualities which distinguished it from other contemporary display facilities either commercially available or in use in research installations. Since 1967, when this display system became operational, there have been many improvements in graphic output facilities. However, it is worth emphasizing those aspects of our system that are unique or of unusually high quality. First, and perhaps the most significant feature of the system is that it possesses the capability of an electronic resolution of 4096 positions along both the x and y axes for twenty-four bit words with twelve bits for x and
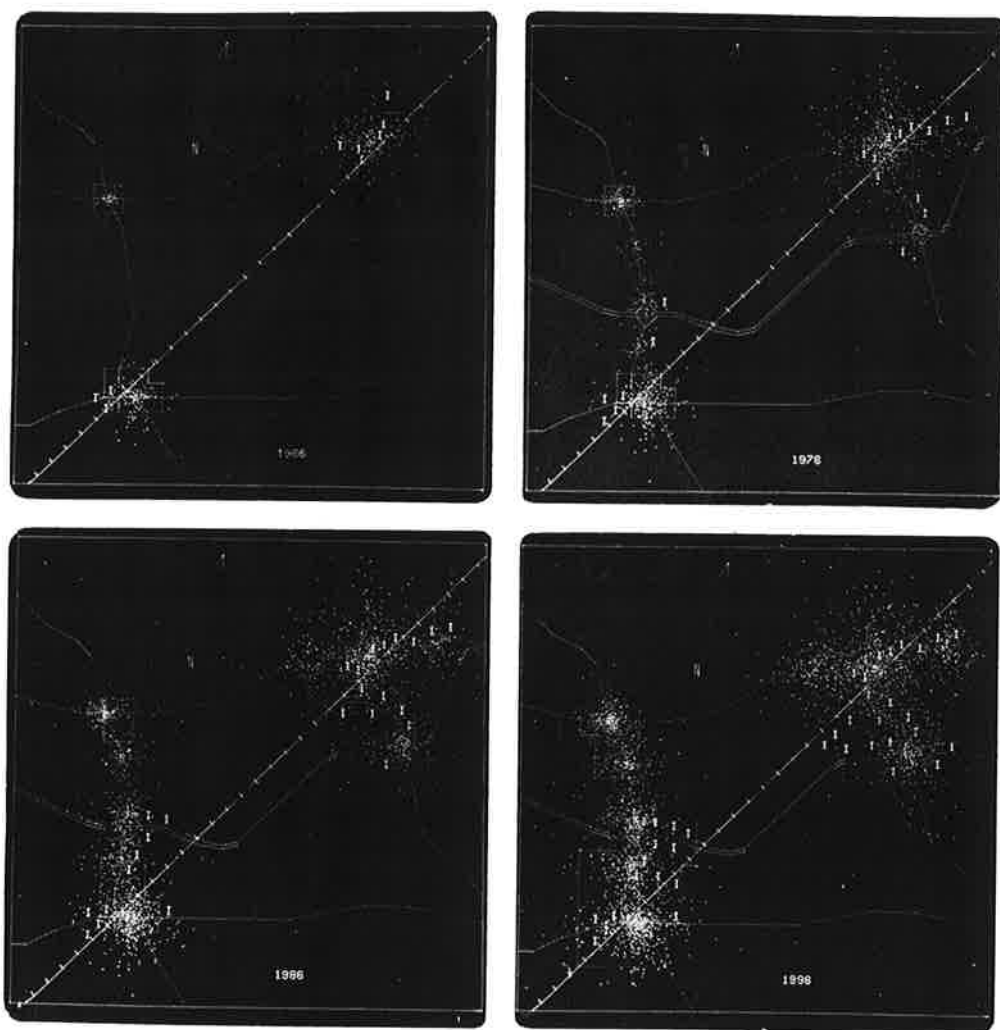
Fig. 26. Enlargement of selected years for Southern alternative.

twelve bits for y. Unfortunately, the CRT is not of sufficient quality to exploit this capability, and we actually operate with 2084 resolvable points in the center of the screen. Nevertheless, our operational capability, let alone our electronic potential, compares quite favorably with other systems which usually operate with a resolution of 1024×1024 positions. Second, we have developed a very flexible reproductive system which can accommodate a variety of camera units including: a Mitchell 16-mm animation camera; a 70-mm roll film camera; a 35-mm camera; and, a polaroid camera. The photographs included in this article were made using all but the 35-mm camera. Third, the user of the system has available eight operating modes, with the potential of expanding to sixteen. The modes being used at this time include: point plotting; graph plotting using t as the independent variable; graph plotting using y as the independent variable; a matrix mode which may be used to construct special symbols; line segments; continuous line generating; character typing; and a TV raster for shading. Fourth, by changing the interface unit the
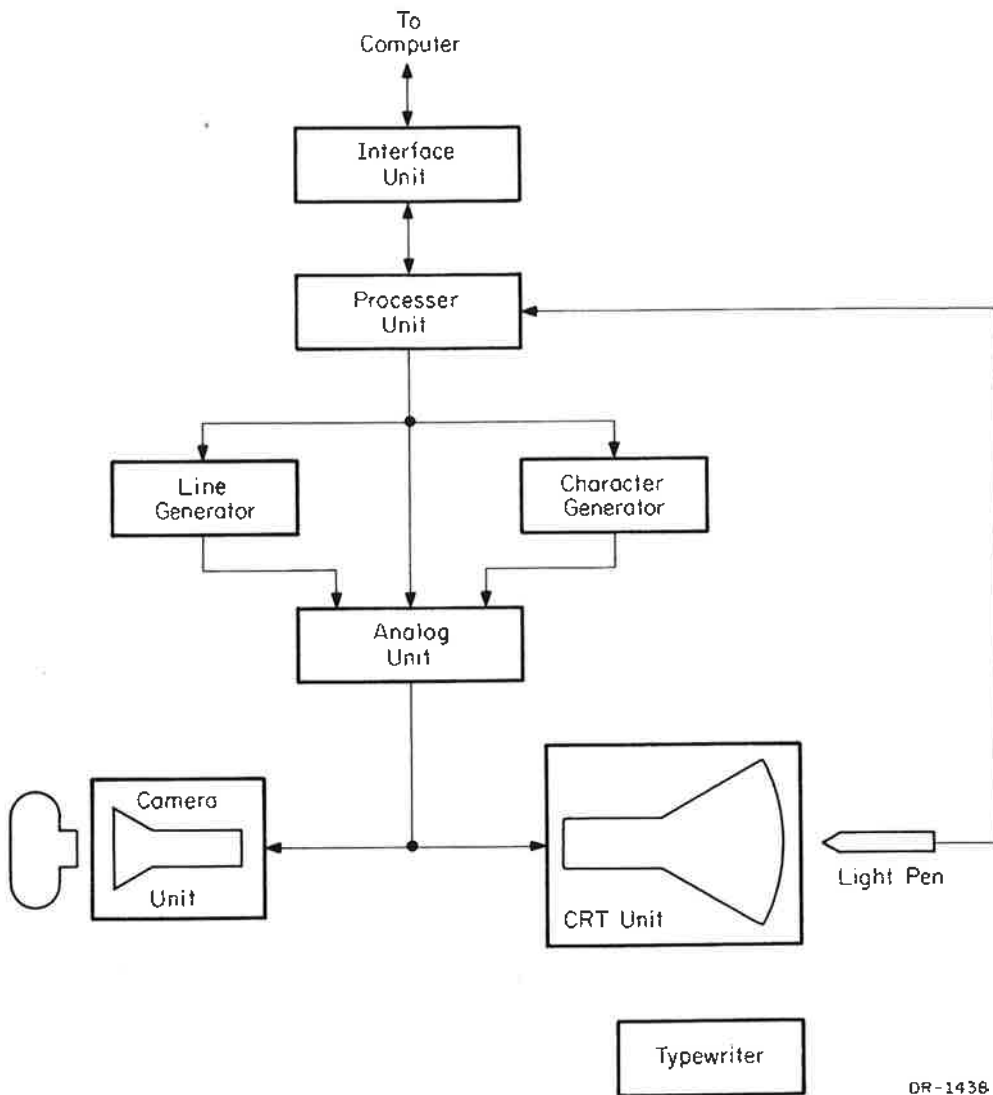
Fig. 27. Block diagram of display unit.

system can be adapted to most computers. Since this is the only portion of the display that is computer dependent, the interface unit has been designed to operate with our CDC 1604 computer. Fifth, the CRT unit is a Fairchild Type 737A Large Screen Indicator containing an electrostatically deflected 17-inch rectangular cathode ray tube and x and y deflection amplifiers with a full output band width of 1 megahertz. Slaved to this unit is a magnetically deflected, electrostatically focused 5-inch CRT for high resolution (1000 lines per inch) photographic recording. Both moving pictures and stills may be made with this camera unit by either manually or automatically operating the shutter unit by the computer program. Sixth, the system is designed to operate at speeds of 333,000 points per second, 50,000 characters per second, and 16,000 lines per second. Seventh, and finally, the system employs two means of communicating with the computer—by typewriter or by light pen. The display typewriter can be used as a substitute

for the 1604 typewriter and can function either as a keyboard input or as an output device for producing printed copy. The light pen interacts with the computer program directly from the face of the CRT by detecting light emanating from a point on the CRT and, after assembling the word, mode, and control bits in the 24-bit light pen register, passes this information to the computer.

In general the display system consists of eight functional units (see Fig. 27) and includes the following: an interface unit which controls the exchange of information between the display system and the computer; a processor unit which performs all arithmetic and logical operations on the data being displayed; an analog unit which converts data from digital to analogue form for the display; a line generator; a character generator; a CRT unit which provides the visual display viewed by the operator; a camera unit for the photographic recording of the data; and the input-output devices for the operator control.

The engineering and programming details of the display system are contained in a report published by the Coordinated Science Laboratory and referenced at the end of this article.

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