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# MODELING URBAN CHANGE

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In this paper the simulation of crisis phenomena in complex social systems is explored. Analogies from complex physical systems containing a "large" number of objects are used to guide the modeling effort. A list processing program is developed that simulates the changing racial balance in urban areas.

ONE ROAD to a better understanding of the workings of urban systems is through simulation models. Unfortunately, for many this road has turned into a "primrose path". Data preparation and monster computer demand have often spelled the demise of these efforts. "Can we do better without doing bigger?" is a question that is worth asking. I would like to suggest that thinking more about the nature of the simulation itself would be part of the answer to this question. By using simulation techniques more suited to the kinds of problems that are encountered, much of the frustration of model builders could be avoided.

The problem I would like to look at here is the simulation of crisis phenomena. In crises, systemic transitions take place rapidly compared to systemic lifetimes. I will deal specifically with the racial transitions of neighborhoods. What I will try to do is to show how some ideas that are useful for understanding complex physical systems are helpful in understanding complex social systems. These ideas will be applied to modeling racial change. My emphasis, however, will be theoretical and conceptual.

## TIPPING POINTS

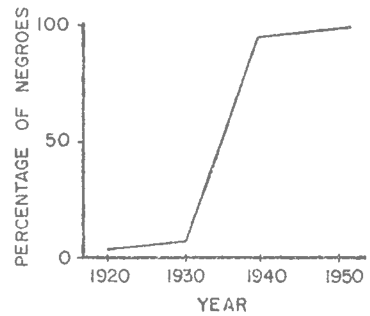
What are the "facts" about how the racial balance of neighborhoods change? Otis and Beverly Duncan have done extensive studies of the process [3]. They, and others, suggest that there may be a value of the racial balance (Black/Total = $r$), which if exceeded in an area, results in the area going all black ($r = 1$). This number is called a "tipping point". The figure below, an abstraction from the Duncans' data for many neighborhoods, is suggestive (next page).

The Duncans distinguish four stages in the process of racial change: penetration, invasion, consolidation and piling-up. There is some disagreement whether there are tipping points evident in all cases of racial change [articles by Wolf and Rapkin in Frieden (1968)]. For the moment we can say that such behavior occurs often. This is the kind of crisis phenomenon I will try to simulate here.

## SOME CRITERIA FOR A MODEL OF CRISIS

What should be required of a model that simulates crisis phenomena? First, *it should be possible to simulate rapidly changing situations.* A model that set all variables to a constant would fail this criterion. More seriously, we want a model which allows a system to be in a variety of distinguishable states (integrated vs. segregated) and which can show rapid transitions between them.

Second, *the model should be able to show these changes without having corresponding rapid changes in some exogenous variable.* For example, if the in-migration rate of blacks into an area were exogenous to the model, it would be comparatively easy to rapidly change the racial balance by increasing this in-migration rate substantially.




Third, *it would be desirable if time were an explicit variable in the model.* Some simulation models exhibit crisis phenomena, but the "rapid" changes are not explicitly in the time variable, but are with respect to some other variable, such as the fraction of the total population that is black. We might see that by changing the fraction of blacks from 30 to 40 per cent we get a "clumping" in the spatial distribution, characteristic of segregated systems. But this does not seem to capture the essence of the crisis problem. Time is a real variable in social policy. It should be explicitly shown.

Fourth, *such a model should be capable of going from individual behavior* (*micro-level*) *to group behavior* (*macro-level*). If we know the likely responses of people to certain levels of racial balance (will they move? will they settle? . . .), we can then use such a model to predict how the large system evolves. The alternative to this is a model that deals in large system variables to predict changes in other large system variables (a macro–macro model).

Fifth, *the model should allow for interactions among the individuals at the micro level.* This requirement is somewhat less obvious than the others. I include it since the kinds of behavioral data that we might get would often be of this sort (will you move if they move? . . .). More importantly, and something that will be discussed further on, it is likely that the *interactions* among individuals is the source of much crisis phenomena.

The manner in which criteria four and five are implemented will turn out to be crucial. Our sixth criterion is that *the simulation should use discrete events, as contrasted to continuous approximations* (*e.g. differential equations*), *in representing the interaction process.* Again this criterion will be explored further on in this paper.

## RELATED AND PREVIOUS EFFORTS

I shall now look at some simulation efforts that are related to the problem at hand. Not all deal with racial change; my concern is mainly with their technique.

Orcutt and his co-workers have been working on micro–macro simulations of economic systems for some time [14]. They simulate the various events happening to households in their economic lives, keeping track of them in a list format. Bookkeeping is done on the list to get values for system variables. The only interaction between the actors is when they get married; this involves some complicating computer technique. Orcutt's concern is not with crisis *per se*, but with respect to criteria three, four, five and six, the model is good.

Other economists have tried to simulate business cycles and other crises. Reflecting current macroeconomic theory, these models are of the macro–macro kind. The best of them fulfill the first three criteria.

Schelling approaches the racial balance problem more directly [15]. He is explicitly concerned with developing a micro–macro model of crisis. But he does not deal with the time variable. The actors in his models interact with each other. His main concern is the stability of certain spatial forms, the possibility of "tips" taking place, and the influence of boundaries and dimensionality in such processes. Some of the results of the first model reported here are similar to those he achieves.

Forrester's model of urban dynamical processes deals with economic development [5]. His model is explicit in time, macro–macro and seems to be able to show fairly rapidly changing transitional effects. He uses aggregate categories (workers, managers . . .), and difference equations to work out the relationships. Since he does make explicit behavioral assumptions about the actors, his model might be called micro–macro. But since it does not deal with them as individuals, I withhold this designation.

The various land-use models developed in the early sixties by Lowery and Harris, among others, were the most famous of the primrose path monsters. These models incorporated time explicitly, might have been able to show crisis effects, but they were macro–macro in the sense given for Forrester's. How they solved the spatial distribution problems had little to do with time, and a lot to do with the stability of the solution (Lowery) or the maximization of rent (Harris).*

Finally some of the spatial theorists have tried to deal explicitly with the problem of segregation. Morrill developed a model in which individual actors interacted. His interest was in the spreading of segregated areas and not their time development [13]. Hägerstrand has a similar interest in studying the diffusion of rumors [7].

A descriptive analysis is provided by Levine [11]. He writes a simple differential equation to account for the data, but this does not fit any but the first criteria.

The various results achieved by these models is suggestive of what could be done if all six criteria were met. That is what I shall try to do here. I will do so in two steps.

The first model just tries to see if we can have a fairly simple model which meets the criteria. Time plays an implicit role in that we are looking at the filling up of an empty area—as it fills up time goes forward. This will show that some simple behavioral assumptions about individuals results in interesting group behavior. After describing this model, I want to suggest how time could be brought in more explicitly and then look at a second model.

## MODEL I

In this first model, I am trying to simulate the spatial character of a segregated neighborhood. I want to make some simple behavioral assumptions about the settlers, let them fill up the area and measure the degree of segregation.

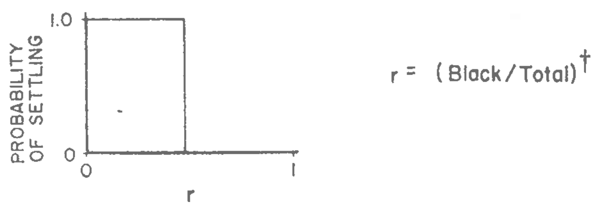
We start off with a grid of 100 by 100 of places to live. It is empty with 10,000 locations in which to settle. The incoming migrant is equally probably Black or White in the runs

* See [8] for a survey of this "business".

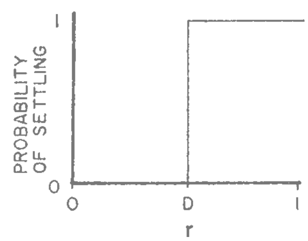
reported for this model. He chooses a random location to settle, and if it is unoccupied he tests if the racial balance is satisfactory. If so, he settles. If not, we try for a different location. This continues until he finds a place to settle.† We then introduce a new in-migrant into the area.

We now look at the racial tests for Black and White.

If the settler is White, we check, according to the probability distribution given below, whether or not he will move in. It expresses a preference for Whites to live near each other.




We have a similar requirement for Blacks. The probability distribution is:




In this model, preference by a race for other members of that race and discrimination against one race by another are not distinguished. For example, the above distribution may be interpreted either as Blacks prefer to live near each other *or* as Blacks being forced to live near each other.

In order to initiate the simulation, Blacks or Whites can settle without meeting these requirements in empty neighborhoods.

After we have settled about 5000 families in this area we stop the simulation and measure the amount of segregation. We choose 50 Blacks and 50 Whites and measure the fraction of Blacks in the area around which they live and histogram that distribution.‡

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* The racial balance will be designated by $r$.

† This suggests that we stop introducing new in-migrants before the area is filled. At a certain point it will be very difficult to satisfy the criteria.

‡ The measurement of segregation patterns is an old problem [4]. In this paper we shall use a very simple measure of segregation. What we do is choose a random number of people who live in the area and measure the ratio of Blacks to the total number of poeple in a *small* area (5 x 5; a "neighborhood") around where they live. We histogram this distribution of racial balance for Blacks and for Whites. After normalizing, we get a probability distribution of racial balance for each color. It is clear that this kind of measurement will give identical distributions for Black and White if we have a completely integrated area. We shall see that highly segregated areas give entirely different distributions since in that case Blacks will have a very high probability of having the racial balance be *one* in their area and Whites will have it equal to *zero*. (See [16] for a further discussion of indexes.)

I want to discuss some results (Fig. 1) for a series of runs where only discrimination with respect to Blacks is encountered. This implicitly has an effect on Whites, but Whites in these runs have freedom to settle where they wish.

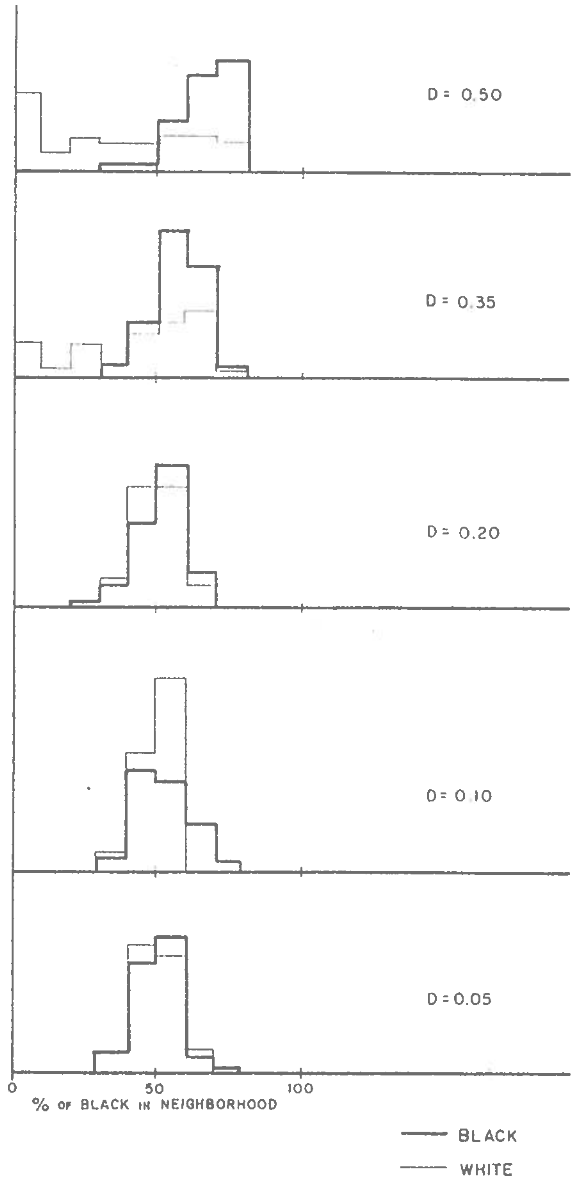



FIG. 1. Racial balance distributions for Blacks and Whites for different values of the discrimination parameter $D$. See diagram on page 44 for a definition of $D$.

We see that, for low amounts of Black discrimination, we get "identical" distributions of racial balance in the "neighborhoods" of Blacks or Whites. As Black discrimination increases, these distributions diverge and segregation increases.

When I originally ran this model I got some unexpected results. I got the Whites in the ghetto and the Blacks spread everywhere else as is illustrated in Fig. 2. This seemed rather strange. Then I realized that all I had *in that early run* was the preference that Whites live near each other. I did not have discrimination against Blacks (or preference that Blacks live near each other) so that net effect is that Blacks could go where they wished, and wherever they went they kept the Whites out. The situation rapidly reversed (Fig. 3) when I added discrimination against Blacks so they could not settle where Whites were.

The model suggested here represents a theory of the interaction of individuals and could be erroneous. For example, the influence of a strong exogenous force such as new sources of employment or new areas opening up, such as the suburbs, are not taken into account in this model. We also start out with an area which is blank. This is rather artificial and can be changed, as will be seen subsequently.

## SOME HEURISTIC SUGGESTIONS

The first model has shown, not too surprisingly, that it is possible to go from fairly unspectacular individual behavior to some rather well defined segregation patterns. The question we still face is how are we to incorporate time dependence into this model? Several heuristic hints are available to us.

The experiences that physicists have had in trying to understand solids and plasmas is illuminating. Their problem is to understand the behavior of a large number of objects interacting with each other, where the interaction produces quite systematic effects (crystalline solids and plasma instabilities). From statistical mechanical studies, it is found that the sharpness of phase transitions (our crises) becomes greater as we go to a greater number of interacting molecules. Studies of the Ising model point up the importance of dimensionality. One dimensional systems are too weakly bound (in the sense of the number of bonds) to have phase transitions, while two dimensional models seem to be fine [9].

The natural question to ask is how many molecules are needed to get a fairly sharp transition (gas to liquid, integrated to black)—$10^{22}$ or 10? From computer experiments it is clear that just a few hundred molecules are sufficient [1]. Birdsall (University of California, unpublished) has tried to do studies on plasma instabilities. Seventeen thousand particles are sufficient for his studies. More significantly, he finds that he need not compute the interaction of each molecule with every other molecule. He can use the mean field due to all the other molecules to figure out how a molecule interacts with its environment. This is especially suggestive. For our first model we did not check on how a person who was moving felt about each of his neighbors. All we knew was the proportion that was black—which is an averaged field-like quantity.

For those not well acquainted with the physics problem a more graphic (though somewhat simplified) example should help. Consider a set of dominoes in a complex array. A few dominoes beginning to fall is sufficient to cause all of them to fall. In the figure below, two configurations of dominoes are shown.

FIG. 2. Spatial distribution of Blacks and Whites when there is a preference for Whites to live near each other. (*=Whites; 0=Blacks.)

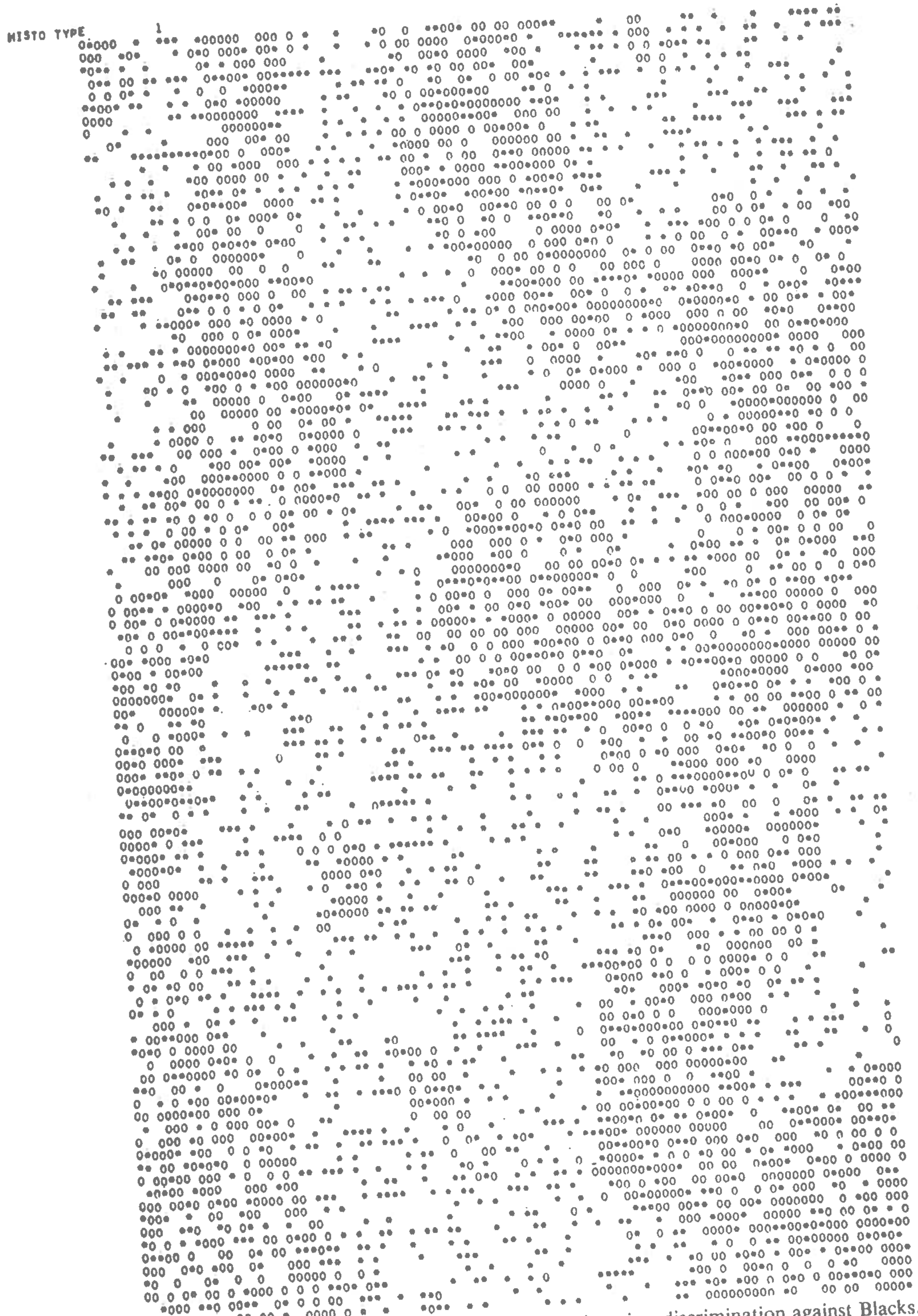



FIG. 3. Spatial distribution of Blacks and Whites when there is a discrimination against Blacks. (*=Whites; 0=Blacks.)

A simple picture tells you all you need to know about configuration *a*. If it takes $t$ sec for one domino to fall, then after $nt$ seconds they all will be down. This simple picture is inadequate for case *b*. If we let any random domino fall, how do we know how long it will take for all to fall down? Perhaps there are closed circles of dominoes within this configuration. Dominoes on the periphery of the circle may cause each other to fall but those inside will not.

We might conclude from the above discussion that if we want to simulate crisis phenomena, we should build into a model a natural procedure which permits many actors to interact with each other at one time. Another implication, which follows from the stochastic and discrete nature of these physical models, is that we should not expect to get most directly at these problems through analytic procedures, since fluctuations are the basis for the beginnings of phase transitions.*

What should be the technique used to simulate these complex multiply interacting systems of individual actors? The process of systems simulation, currently best represented by GPSS and SIMSCRIPT programming languages, seems most natural. The list processing techniques used in these programs are reminiscent of Orcutt's work. In discussing gaming simulation, Dalkey points out the advantages of a list processing procedure for handling fine details of the simulation procedure [2].

A final heuristic idea can be found in a discussion of the problems of understanding complex systems of queues [10]. This is similar to the segregation problem, especially if reformulated in terms of "people are *waiting* to get a house . . . " I quote:

> The complexity of such systems defies exact mathematical analysis. The systems will require essentially new ideas if they are to be fully understood. I believe a source of inspiration can be found in the many-body theories that underlie so much of modern physics as ways of describing highly complex interacting systems such as the molecules in a gas.

## MODEL II: A CRISIS IN TIME

We now want to use the suggestions that have been made in the previous section to develop a model that exhibits crisis behavior. Our center of attention will be shifted from that of the first model. Rather than look at the spatial patterns of segregation, we want to look at the time development of such a state. Therefore, I will characterize each neighborhood by its racial balance, use neighborhoods with fixed boundaries and ignore the exact spatial patterns within a neighborhood. Our initial condition will be different also. We start out with neighborhoods which are partially filled and all white. These initial conditions are reminiscent of what has happened to many central cities.

Now on to the model that is actually programmed.

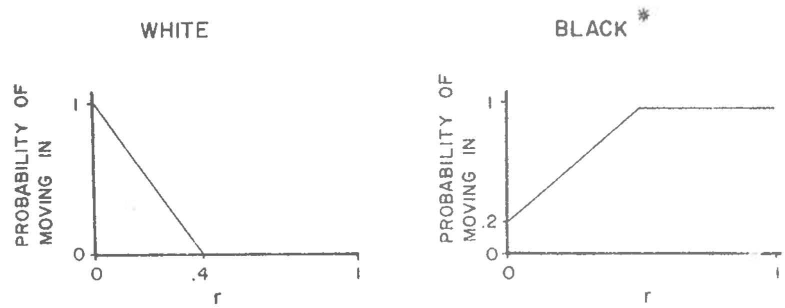
We start out with a grid of neighborhoods, $10 \times 10$, each neighborhood having $N_0$ occupants, all of whom are White. The total population is $100\ N_0$ Whites at zero time. We generate $n$ new in-migrants into the area each unit of time, with $B$ per cent of them Black. The history of a settler is:

> He enters the area and randomly chooses a neighborhood. If the neighborhood has room, *and* if he passes a *discrimination criterion*, he moves in. If not, he waits $t_1$ units of time and tries again (and again . . .). After a certain amount of time, $t_2$, which interval is dependent on color, he gets "discouraged" and leaves the area.

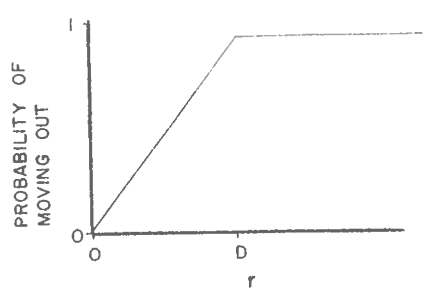
* Investigations of fluctuations and phase transitions can be done analytically, and I would expect that these techniques would prove useful eventually. What I am suggesting here is that analytical techniques are not the best way to start.

When, and if, he finds a place that is acceptable, he moves in. If the settler is Black, *we then test and see if some Whites want to move out*. If they pass the move-out criterion, we generate a new member of the list of movers and put him through the process. If one White moves out, we try for another.

The discrimination criteria are distributions that give the probability of moving-in dependent on the racial balance. I have used simple shapes for these distributions (pending empirical investigations), and parameter values that should yield segregation, as suggested by the first model.




The moving criterion is a similar distribution. It gives the probability of a White moving out, given a certain racial balance. It would look like:




*D* can be varied to get the different kinds of moving behavior.

## IMPLEMENTATION AND RESULTS

Model II was implemented in FORTRAN for the CDC6600. Rather than use GPSS or SIMSCRIPT, list processing simulation languages, a simple list processor was written in FORTRAN. This is somewhat easier than reading the manuals for the higher level languages. Short (15 sec) runs on the machine were sufficient to get the indicated results.

Figure 4 gives a flow chart for the model. The chart, for the most part, should be self-explanatory. The only part where the flow is not apparent is in the *reaction* boxes. In a reaction situation we have the generation of events where people are dissatisfied with

* At $r = 0.0$, we set the probability to be non-zero. If it were zero and the neighborhood were all White to start ($r = 0.0$), then Blacks could never settle.

what is happening in their area due to the action of someone else. In the reaction box, we have the possibility of someone deciding to move since the racial balance of his area has changed.

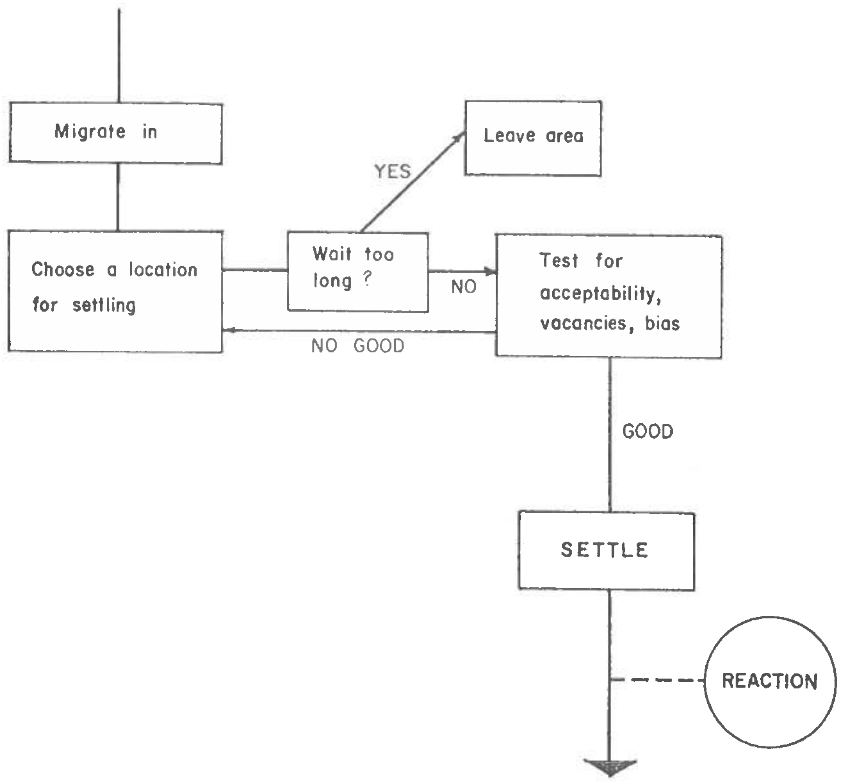



FIG. 4. Flow chart for Model II.

I have given results for three cases: Whites move easily (I), Whites move with some difficulty (II) and Whites stay put (III).

What do we mean when we say that Whites move easily or not? We have control of two variables. The time after which someone gives up and leaves the area, $t_2$, can be adjusted. For Whites, for case II, $t_2 = 30$, while for cases I and III, $t_2 = 10$.

Another option is to adjust the probability of Whites moving, if a Black moves into the area. We can change the point at which the probability curve saturates (point $D$) and this is what distinguishes cases I and III.

The values for these variables are summarized in the chart below:

TABLE 1

| | Case | $t_2$ | $D$ |
|---|---|---|---|
| Easily | I | 10 | 0.2 |
| Intermediate | II | 30 | 2.0 |
| Stay put | III | 10 | 0.66 |

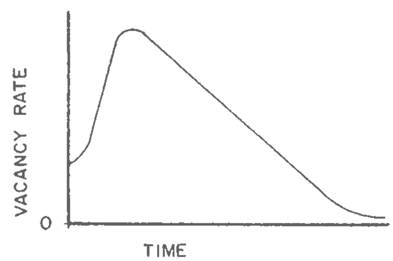
Results for all three cases are given in Fig. 5. Some of the hundred neighborhoods will go all Black, others will remain integrated. If we divide up the neighborhoods this way, we can look at prototypical time histories of the racial balance. Also given is the fraction of neighborhoods that go Black. In Fig. 6, I show what the raw computer output looks like for three neighborhoods. Here, the number of blacks in the area as a function of time, is also plotted.

We note immediately, that the more likely the Whites are to move, the greater is the number of all Black neighborhoods.

As can be seen, we do obtain the rapidly changing phenomenon characteristic of a crisis. The racial balance in some neighborhoods can change *very* rapidly, because *both* Blacks are moving in and Whites are moving out. This evolution is similar to the analysis offered by the Duncans. The piling up process does not occur in this model since we limit the occupancy to 100 families/section.

Note also that for some neighborhoods, there is no saturation effect; a small number of Blacks move in and there is stability. In this case the crisis is resolved in a non-catastrophic fashion.

Let us look at the neighborhoods which go all Black. A difference between cases I and II is not illustrated in the figures. For case I, the Whites tend to abandon a neighborhood before it is filled with Blacks. Thus $r = 1.0$ well before the neighborhood is fully occupied. A substantial vacancy rate exists some time while the neighborhood fills up with in-migrating Blacks. The vacancy rate has the following behavior in time:




For case II, the area tends to have a low vacancy rate. The Whites do not flee, but rather they "sell" directly to the Blacks.

What about the integrated neighborhoods? For case III, we see that they become about 30 per cent Black, just filling up the vacancies that existed at the beginning of the model. Note that for this case, there are no segregated, all Black, neighborhoods.

For the other two cases, the integrated neighborhoods are quite interesting. When the Whites move easily, they can take over an area, create zero vacancies, and no Blacks can move in ($r = 0.0$). Case II is such that some Whites do move out. The percentage of Blacks is thus 20 per cent rather than 30 per cent for case III.

The Taeubers' [16] research on segregation suggests that the rate of change is dependent on the migration rate of Blacks into an area compared to that of Whites. Not all areas will show the behavior that the Duncans observe [3]. While it may be true that tipping behavior would be characteristic of the single race in-migration I simulate here, there is no reason to believe that we would get such a transition if different conditions prevailed. In our cases II and III where Whites are reluctant to move, we are in effect preventing the in-migration of Blacks.

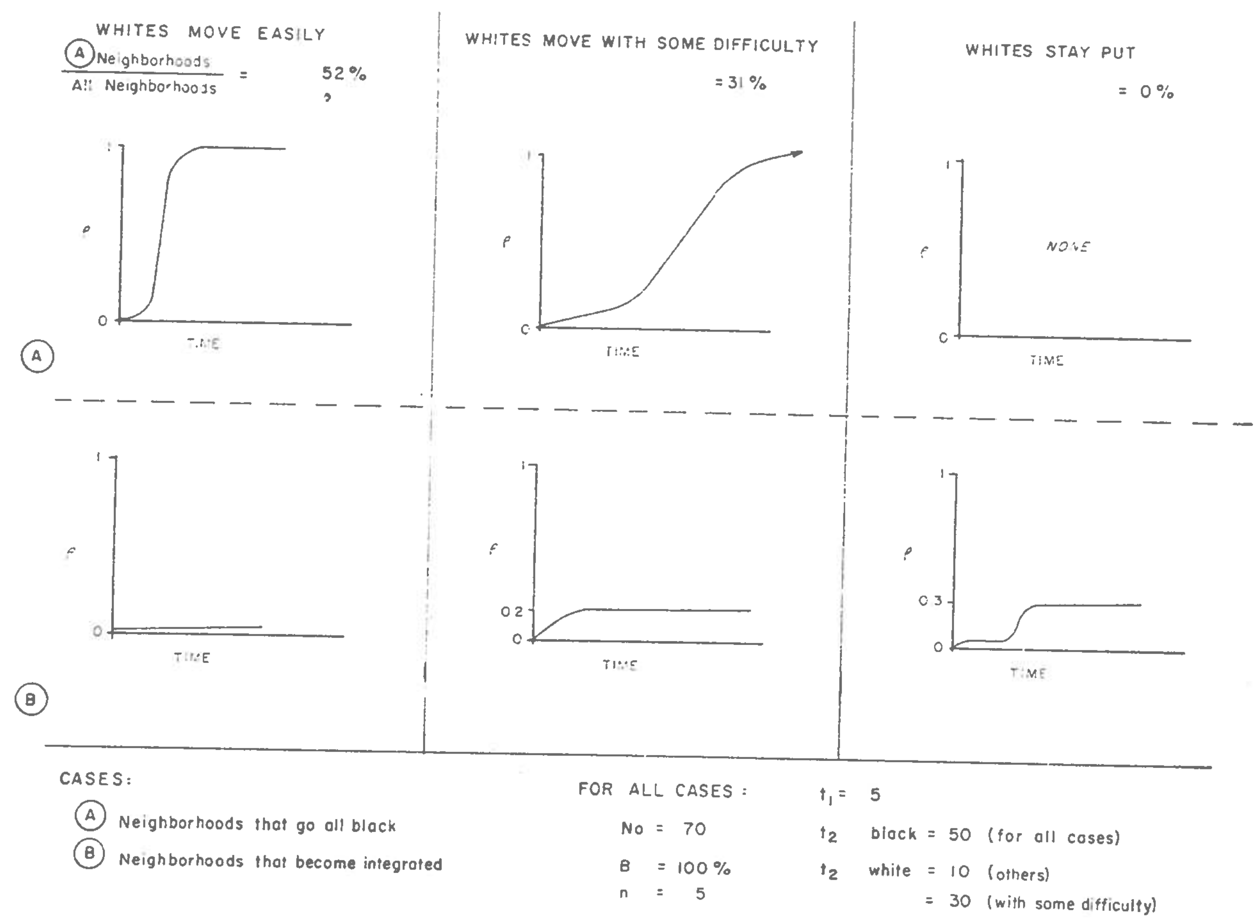



FIG. 5. Some results for Model II.

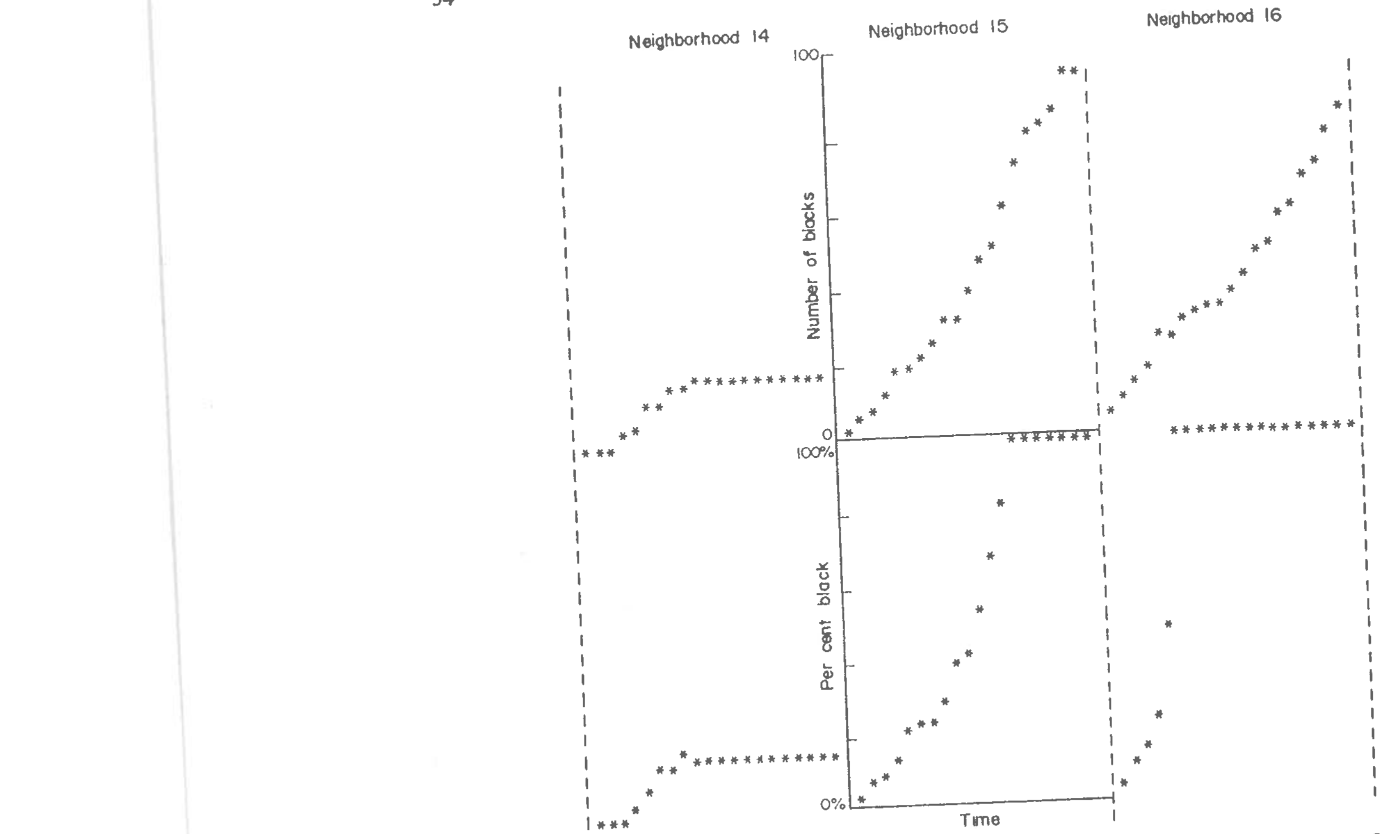



FIG. 6. Computer printouts of three neighborhoods' racial history. The maximum number of persons per neighborhood is 100. A 1000 units of time are accounted for. The upper part of each graph gives the history of the number of Blacks, while the lower part gives the history of the racial balance.

A recent empirical article provides for some illuminating comparisons with what we have learned here. Molotch [12] has studied the racial change in a community to see if there are massive move-outs characteristic of case I behavior. The results of the investigation suggest that a case II process would best represent the data. The racial change was slow and was more a function of Blacks being the ones who bought houses that the Whites wanted to sell, than simple discrimination behavior. What is suggested for this kind of modeling effort is that a model with Whites just moving out for other reasons, with no discrimination, might achieve results similar to case II.

## CONCLUSIONS

I have tried to show here how we might build crisis into simulation models in a natural way. What seems to be necessary is a small number of individual actors (a few hundred), a possibility of actors influencing each other (and thereby causing feedback effects) and an explicit consideration of the time variable. Ordinary list processing procedures seem to be effective in implementing these efforts.

What needs to be done in subsequent work is a calibration effort. If we can get data on how people behave in these kinds of situations, feed this into the model and obtain predictions for the probability of obtaining a segregated area, we can check the model. It may turn out that even if such a model can achieve a useful simulation of crisis, the true causes of some crises will lie in other effects. This is what we would like to find out.

*Acknowledgments*—These ideas were originally developed at Nevis Laboratories of Columbia University. I want to thank the Seattle Research Center of Battelle Memorial Institute for giving me the time and leisure to pursue them. More recently, I have continued this work at the Lawrence Radiation Laboratory, Berkeley, and at the Center for Planning and Development Research. My colleagues, Richard Meier, Harry Saal and Robert Fuller, helped me in thinking through these problems.

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