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AGENT-BASED MODELS OF URBAN INDUSTRIAL SPECIALIZATION

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ABSTRACT

Urban industrial specialization is advantageous because a set of related industries can share suppliers, expert workers, managers, and engineers, and because there are positive economies of scale and scope associated with such specialization. In the face of the limitations of anything but the most simplistic mathematical model of such a process, an agent-based model is a good way to gain insight into the evolution of such urban specializations, if related agents are attracted to one another. After an initially random placement of establishments, the system evolves so that related agents move near one another. In the version of the agent-based model described herein, there are only two types of establishments: core establishments and supplier establishments. Each establishment belongs to a particular industrial sector. There is a directed bipartite graph connecting supplier sectors to core sectors. The result of this is the self-organized emergence of urban industrial specializations. The "cities" that emerge are not of uniform size, but vary substantially in size, as they do in the real world.

Keywords: Urban geography, supply chains, urban economics, economic simulation

INTRODUCTION

Actual markets function much differently than the idealized markets of neoclassical economic theory. In neoclassical theory, space does not exist, nor do social networks; buyers meet sellers in a perfect auction market. In real markets, there is a distribution of sizes of firms, and firms operate in social networks and in space. Relatively few large firms tend to dominate particular industries. For instance, banking is dominated by large banks such as Citicorp and Chase, aerospace by Boeing and Airbus. Even in industries such as automobiles, a dozen or so huge firms dominate the world market. And trends constantly move toward further consolidation. This is because larger firms can take advantage of economies of scale, scope in production, and, equally if not more importantly, scope in marketing. Thus a large firm like General Electric is constantly acquiring smaller, more entrepreneurial firms, so that the advantages that GE has in both production and marketing can be wedded with the innovations of these smaller firms in order to take more profitable advantage of these innovations.

Urban history is inextricably intertwined with the histories of large firms. Of course, Detroit is historically associated with automobiles. Hollywood is associated with the large motion picture studios. Silicon Valley is associated with the computer industry. New York City is associated with many industries, notably investment banking and the stock exchange (Wall Street), the clothing/design industry (Seventh Avenue), the advertising industry (Madison

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Avenue), and the publishing industry. Other high-wage industries, such as legal, accounting, and medical services, have grown up to serve its diversified economy.

Larger cities tend to have more diversified economies and therefore are less vulnerable to downturns in particular industries. In order to understand why larger cities have more diversified economies, we need to understand the relationship between industrial location and urban growth.

Despite the hype about the importance of small business, large firms still dominate the economies of the economically advanced countries. In fact, many smaller firms exist mainly to serve the needs of the larger firms or of their workers. Thus, a cluster of large hospitals and universities is serviced by many small service firms nearby, such as restaurants, bookstores, and photocopy shops. Or, on an industrial model, a large automobile plant is serviced by a large number of suppliers, making all sorts of components that go into the car, such as the seats, the dashboard plastic molding, or precision parts that are used to assemble the engine.

THE ECONOMIES OF PROXIMITY

The basic idea of economic geography, even in the information age, is that there are economies associated with proximity. (Ironically, one of the best-known industrial districts, Silicon Valley, is itself the quintessential information-based economy, giving the lie to the idea that geography doesn't matter for the most "advanced" parts of the economy.)

Of course, firms do not respond to proximity alone. In fact, they primarily respond to the availability of markets for their goods. But proximity minimizes transportation costs and often transaction costs as well. Even in the age of low communication and computation costs, there are savings associated with face-to-face communications, especially in coordinating complex activities. If economic activities are highly standardized, are not heavily dependent on human knowledge and on the interactions between skilled and/or educated workers, and do not change rapidly over time, then they typically can be done at a distance. However, if one or more of these situations do not hold, there is still typically an advantage to proximity. Firms in a particular industry or set of related industries still tend to locate close to one another. Locating near one another allows suppliers and large firms (OEMs, or original equipment manufacturers) to tap into a shared labor market with specific knowledge of that particular industry.

Workers with skills relevant to this labor market also tend to move to the industrial district as well to take advantage of the "ideas in the air." Often industrial districts are so rich with knowledge of an industry that it is difficult to determine who originated particular ideas, and new firms within the district tend to be born and die frequently. In addition, particular large firms grow up, often rapidly (e.g., Google, Ford, Hewlett-Packard), and come to play dominant roles. Industrial districts have been recognized by economists for a long time; the term "industrial districts" appears to have been first used by the British economist Alfred Marshall (1890, 1920). There is a substantial contemporary literature on industrial districts and the similar concept of industrial clusters, most of which is qualitative, descriptive, prescriptive, and analytical; see, for example, Piore and Sabel (1992), Porter (1998), and Harrison (1992), among many others.

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Supply Chains and the Interaction of Location Decisions

Location decisions of firms are based on location decisions of other firms. If a large firm locates in a particular place, firms that supply it are likely to locate nearby. If one OEM moves into a particular location and attracts workers and suppliers, this may attract another OEMs in the same or a similar industry. This is also true of other large firms in the service industries, such as health care, financial services, and education.

Empirical studies of city sizes have shown that city populations tend to obey a power law. A simple model of population growth can account for such a power law (Krugman 1996). However, a more complex process also underlies this, as people move where the jobs are, and firms move where the people and the other firms are.

Real economies function on a supply chain; that is, a series of inputs creates the final product. Multiple supply chains converge on a single point: the final product. Labor and capital are the inputs to these supply chains. Many workers are skilled and specialized and associated with only one or a few supply chains. This is true of the service industries as well as manufacturing.

Since supply chains have more than one level of supplier, it is an oversimplification to say that the economy can be modeled in terms of OEM-supplier relationships. More realistically, there are relationships between suppliers at various tiers of the supply chain, and then the final supplier-OEM relationships.

The economy could be modeled with agents representing individuals, some of whom are workers, who can hold multiple jobs. There are also nonworking individuals, such as children, the retired, the unemployed, the disabled, and stay-at-home parents, who do not contribute to production that is captured in the market but nevertheless contribute to consumer demand. Each of these could be modeled with an agent, and person-level agents could be grouped into households.

On the firm side, one could model the entire supply chain, but one would need to know the topology of the chain and the relative numbers of establishments at each level. One would also need to know the demand flows that run between each pair of establishments in the chain. Much of this information can in fact be determined from input-output models of regional economies and establishment data, such as those from the U.S. Census Bureau (2002) and U.S. Bureau of Economic Analysis (1997), but doing so would be a rather Herculean task. Finally, one would need to know final demand which is also available from the input-output tables.

Simple Model of the Geography of Supplier Relations

In an initial, simple model, there would be two main types of agents — establishments and workers — and each agent would make decisions about where to locate based on access to markets and proximity, which are related to one another. This is based on the theory that relations between firms, like other social relations (e.g., between friends or establishments), are "sticky" and that firms like to do business with other firms with which they have longer-term relationships and with which they have established relationships of trust. They do not want to

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constantly be switching suppliers in order to get a rock-bottom price, unless they are buying a commodity that is readily available with a reliable price and quality from a large number of vendors. In a fully fleshed-out model, it also would be necessary to model commodities and the price mechanism, perhaps by using a model of trade similar to that used in Sugarscape (Epstein and Axtell 1996).

However, for an initial model of supplier-OEM relations in an urban landscape, it is not necessary to have this much complexity. In fact, it makes sense to start with a simpler model that only has a few features of the more complex one just described. A simple agent-based model can capture the utility associated with proximity by creating agents that respond to proximity alone.

My initial model has just two levels in the supply chain — suppliers and OEMs — and does not model workers at all. It also does not model final demand or the price mechanism. All it does is model the responsiveness of the agents to proximity. However, just because the model is simple doesn't mean that it cannot generate insight. To take this position is similar to criticizing Schelling's (1978) famous model of segregation because it did not take account of housing prices or social class.

Generally, there are more suppliers than OEMs, although the relative number varies in a complex way through the supply chain and is dependent on the industry. Thus, if we are, as a first cut, going to model the economy in terms of relations between suppliers and OEMs, we need to have more suppliers than OEMs.

Analytically, we have a distinction between a supplier *type* and an individual supplier *establishment*. A bipartite graph represents the relations between supplier types and establishment types. Each node in that graph represents a set of individual establishments of that type. When a supplier type node is connected to an OEM type node, this indicates that there are one or more instances of that type of supplier that supply that type of OEM. Thus a single link between nodes in the type graph represents one or more links between instance nodes, which may (and usually are) multiple on each side of the bipartite graph.

Given a fixed number of supplier types and a fixed (different) number of OEM types, there are many possible topologies of such a bipartite graph. For instance, one of the simplest possibilities is the following: we have two supplier types 1 and 2 and two OEM types C and D, where suppliers of type 1 only supply to OEMs of type C, and suppliers of type 2 only supply to OEMs of type D. Thus the bipartite graph consists of two disjoint pieces. Alternately, suppliers of types 1 and 2 both supply to suppliers of types C and D. In this case, the bipartite graph is as completely connected as such a four-node bipartite graph can be.

In my simplified model, with just one layer in the supply chain represented by this bipartite graph, the inputs to the model include the following: the number of distinct supplier types, the number of establishments for each supplier type, the number of distinct OEMs, and the number of distinct OEM establishments for each OEM type. In addition, the graph itself is input to the model.

The urban landscape is a simple square grid of cells. All of the suppliers and OEMs are initially placed in random locations on the grid. Each supplier and OEM agent, taken in turn, is given the choice of moving from its current location to another location in the grid, where a fixed number of random, unoccupied locations is considered. The move is made from the current

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location to the new location with the maximal utility for that agent, if that maximal utility exceeds the current utility. Otherwise, the agent stays put.

There are obviously many options with regard to the utility function. One of the simplest functions that rewards supplier-OEM proximity is to count the number of agents that would be neighbors (in the Moore neighborhood) and are also adjacent in the bipartite graph — that is, a supply relationship could exist between the agent in question and the neighbor agent. The more neighbors and potential supply relationships, the better. A possible enhancement is to attach some disutility to the presence of neighbors of one's own particular type, perhaps after some threshold is reached. This would amount to creating a disincentive for firms to move to a locale if there is too much competition and congestion. If supply relations are in fact "sticky," it is realistic to think that a market would be hard to break into once it is saturated. Such a disincentive is probably a major factor that prevents all the firms and population in the country from "lumping up" in one place (others are the availability of natural resources and the climatic preferences of the population).

Model Results

I have not yet implemented a more complex utility function. Instead, I have limited my experiments so far to experimentation with the topology of the bipartite graph. In the first experiment, there are two supplier types and two OEM types. Each supplier of type 1 supplies to OEMs of type A; likewise for 2 and B. There are 50 suppliers of each type, and 10 OEMs of each type (reflecting the fact that suppliers tend to exceed OEMs in number). Thus there are a total of 120 agents in the system. On one particular run (the runs can differ because of differences in the random initialization of the grid), the 120 agents are found in 99 clusters of adjacent agents across the grid; thus, most agents are initially in singleton clusters.

On this run, the agents are all initially scattered throughout the grid. After 5,000 updates of the grid, in which the system attempts to move each agent in turn to another location, moving it if the new location has more supply chain graph neighbors than the old location, the grid has been updated into 15 "cities," which are either 1A cities or 2B cities. The mean city size is therefore eight agents, and there are a variety of cities of different sizes. The results at the end are shown in Figure 1.

In the second version of the model, there are four types of suppliers, labeled with the numbers 1–4, and four types of OEMs, labeled with the letters A–D. Each of 1 and 2 supply to both A and B, and each of 3 and 4 supply to both C and D. As before, there are 50 suppliers of each type, and 10 OEMs of each type. There are a total of 240 agents, and there are initially 165 "cities," so singletons are somewhat less common than before, because the grid is initially more densely populated.

After 5,000 grid updates, we have 21 cities, as shown in Figure 2. Thus the mean city size is of the same magnitude as before; here it is around 11.4 as opposed to the prior 8. Unlike before, we have some cities that cross over the supplier relations; that is, they contain suppliers and OEMs that are not connected by a relation. This is simply due to the increased overall congestion. However, within these cities, there are neighborhoods that are governed by the supplier relation.

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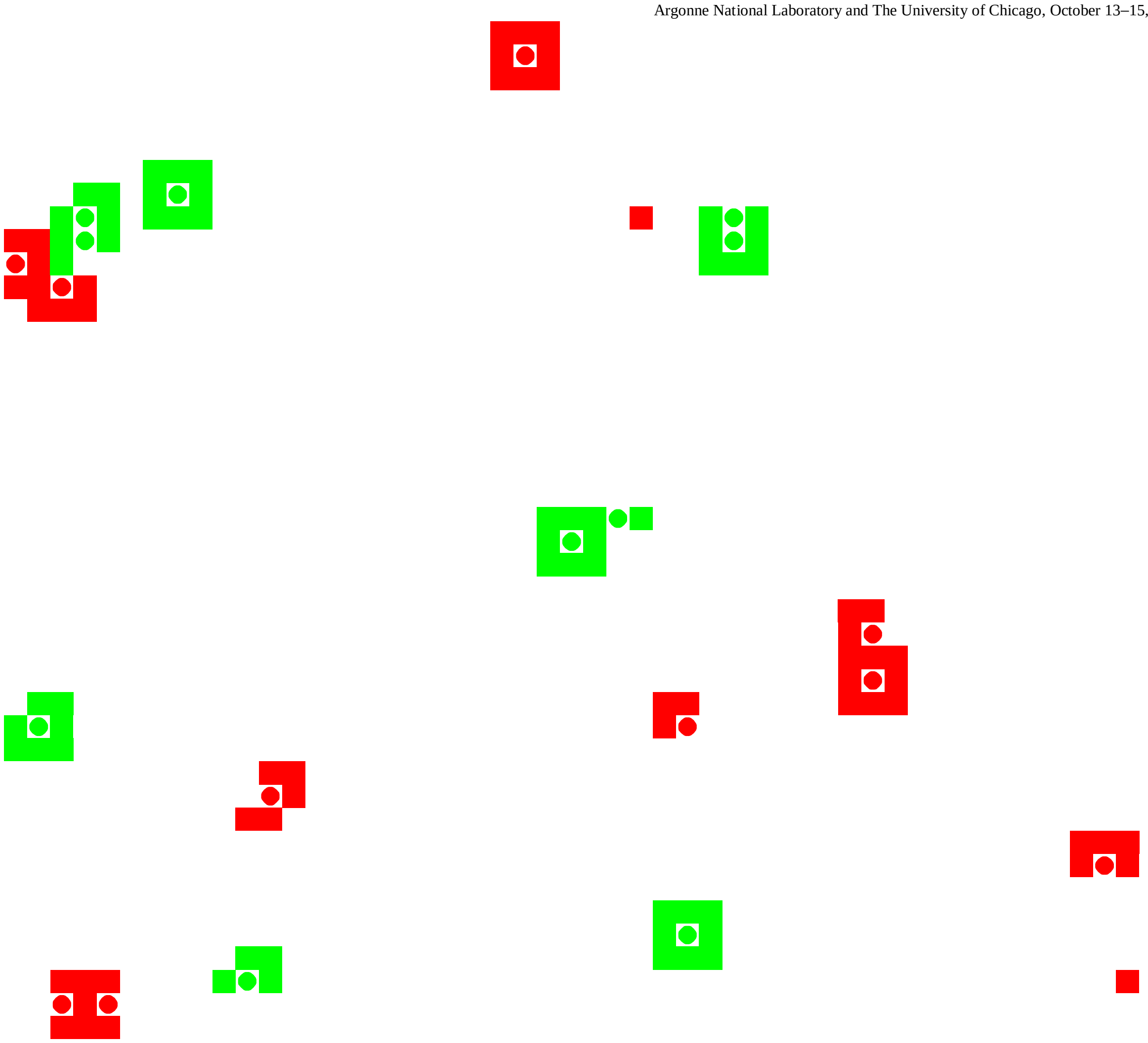

FIGURE 1 State of a grid of suppliers and OEMs after 5,000 iterations; graph topology consisting of two supplier-OEM pairs

Legend:
Red square: Supplier 1
Green square: Supplier 2
Red circle: OEM A
Green circle: OEM B

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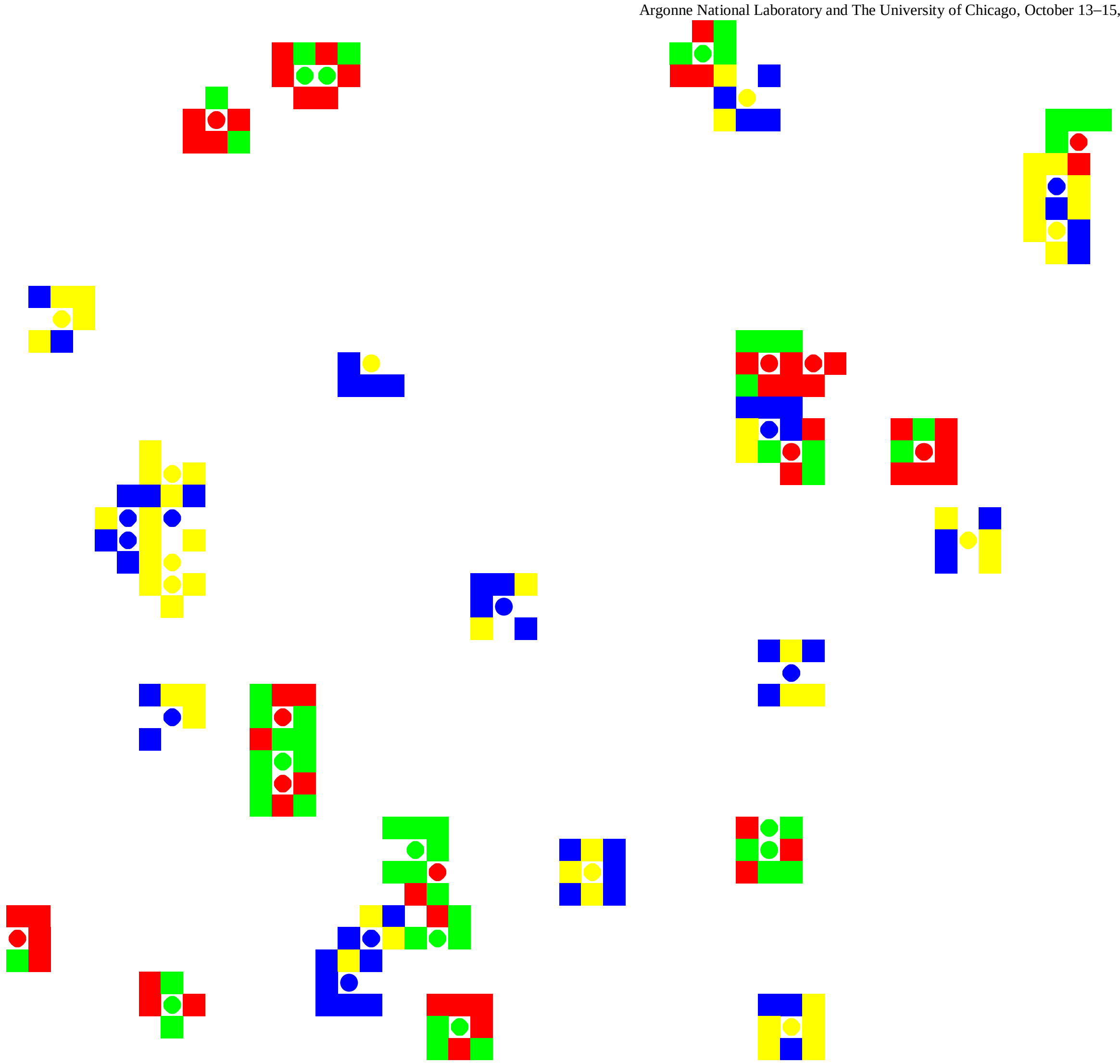

FIGURE 2 State of a grid of suppliers and OEMs after 5,000 iterations; relations between OEMs and suppliers are characterized by two disjoint fully connected bipartite graphs, each consisting of two supplier types and two OEM types

Legend:
Red square: Supplier 1
Green square: Supplier 2
Blue square: Supplier 3
Yellow square: Supplier 4
Red circle: OEM A
Green circle: OEM B
Blue circle: OEM C
Yellow circle: OEM D

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The third version of the model is the same as the second, except that an additional supplier/OEM relation is given, between supplier 3 and OEM B. The result after 5,000 grid updates is shown in Figure 3. This slightly increases the probability of urban clumping, and the number of cities falls to 19, raising the mean city size to about 12.6.

Thus we see that a relatively simple model can account for the emergence of “urban industrial districts.” Further refinements, as I have described, should account for more details of urban economics and geography.

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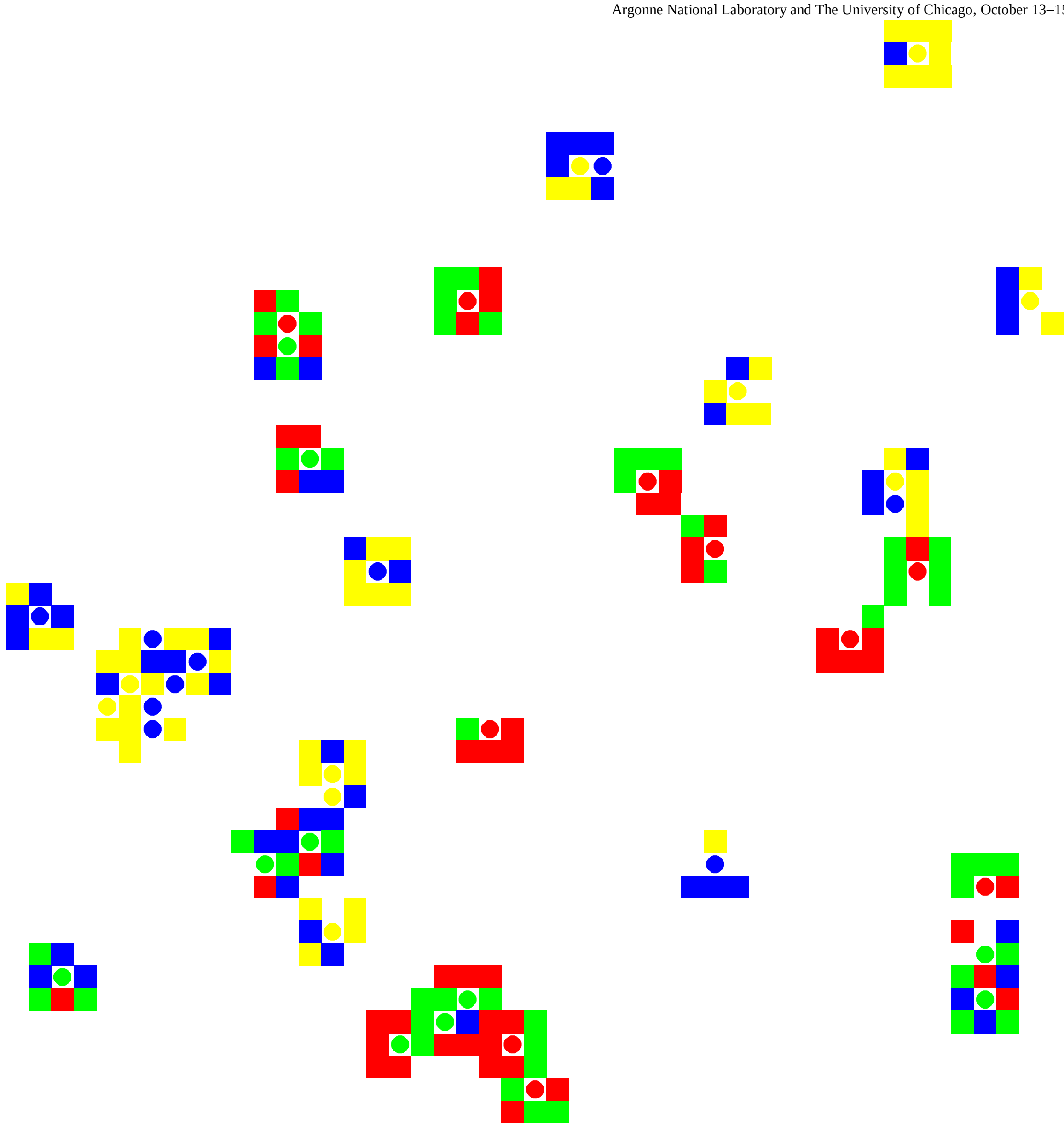

FIGURE 3 State of a grid of suppliers and OEMs after 5,000 iterations; relations between OEMs and suppliers are characterized by two disjoint fully connected bipartite graphs, each consisting of two supplier types and two OEM types, and one additional connection between the two bipartite graphs that would otherwise be disjoint

Legend:
Red square: Supplier 1
Green square: Supplier 2
Blue square: Supplier 3
Yellow square: Supplier 4
Red circle: OEM A
Green circle: OEM B
Blue circle: OEM C
Yellow circle: OEM D

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