The Evolution of Exchange Networks: A Simulation Study (by Phillip Bonacich)

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Outline

Motivation

Networks of exchange opportunities evolve when dissatisfied agents search for new partners.

This paper answers to the following questions:

- Are there stable networks whose participants do not look for new potential partners?
- What do these networks look like?
- How is the outcome of this evolutionary process related to the beginning network?
- What are the characteristics of stable networks?

Research method

Computer simulations are used to explore how networks of exchange opportunities evolve when agents can change positions.

Assumptions of the standard model:

- A set of actors can engage in a limited number of profitable dyadic transactions (e.g., 1 buyer and 1 seller).
- Actors must choose with whom to transact from among a fixed set of other actors.
- Each transaction produces a profit that can be divided between the two participants if they can agree on a division.
- Some actors have more transaction partners than they can possibly transact with; their freedom to choose and reject gives them **power**.

Impact of power

Powerful positions depend on a surplus of dependent positions to which they are inalterably connected. These power differences depend on the immobility of the weaker positions.

For example:

There is 1 seller and 2 buyers. Seller has only a single indivisible product to sell.
$\Longrightarrow$ Seller has power against buyers and probably can use this situation to increase his/her profit. But if one of these 2 potential buyers finds another seller who has no potential buyers then the buyer chooses to transact with another seller.
$\Longrightarrow$ Initial seller looses the power.

Concept of stability

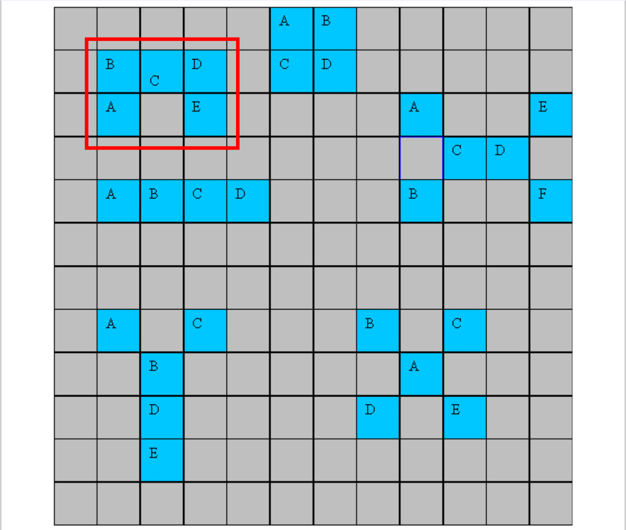
There are two types of stability:

- Stability I: we have the stability of an exchange pattern within a fixed network of exchange opportunities;
- Stability II: we have networks in which there are no dissatisfied actors who are motivated to transform the network of exchange opportunities itself.

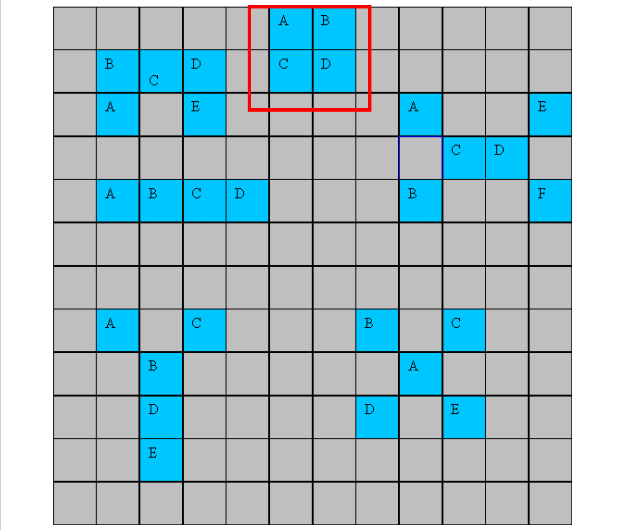
The main types of exchange networks

1. Hourglass
2. Square
3. Dual-Star
4. Star
5. Tee
6. Four-Chain

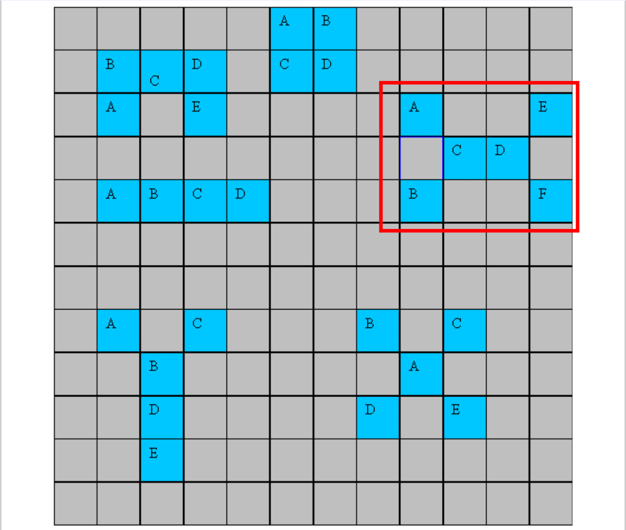
"Hourglass" exchange networks



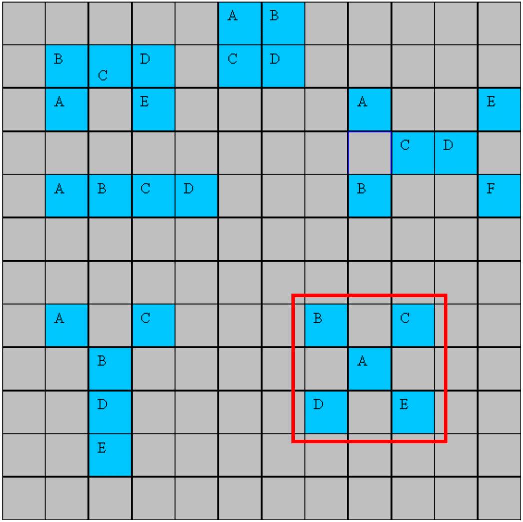
"Square" exchange networks



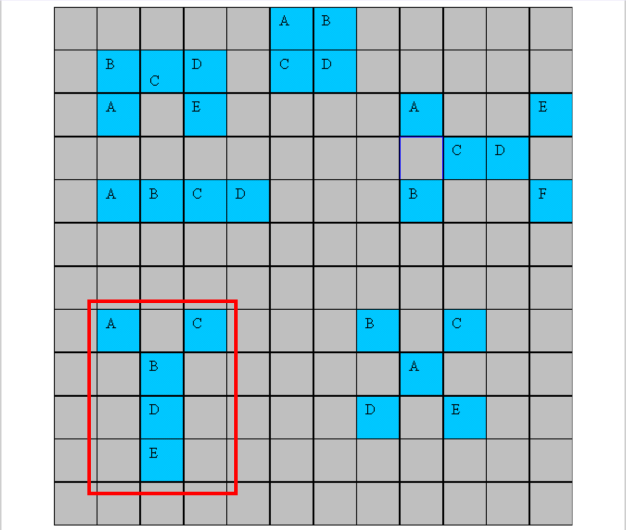
"Dual-Star" exchange networks



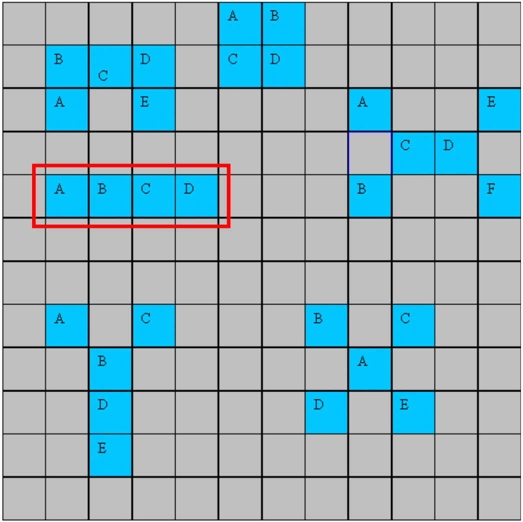
“Star” exchange networks



"Tee" exchange networks



"Four-Chain" exchange networks



Cellular automata

The simulations reported in this paper use cellular automata: the actors are represented by squares on a two-dimensional surface. Actors can trade only with other actors occupying one of the eight neighboring squares. To eliminate any "edge" effects, the board is a torus, in which the top and bottom and left and right are connected.

Advantages of cellular automata:

- Cellular automata produce images that are easy to visualize and understand.
- Simulations with cellular automata can incorporate simple rules for forming and dissolving network ties and for network change.
- The images produced by cellular automata make use of our abilities to recognize and interpret visual patterns.

Cellular automata II: some features

A cellular automata can exist in any number of dimensions, and the definition of neighbor can vary.

Moore neighborhood: pairs of cells sharing a corner or an edge (in 2D, each cell has 8 neighbors).
Von Neumann neighborhood: a neighbor could be another cell sharing an edge (in 2D, each cell has 4 neighbors).

Cellular automata III: limitations of 2D cellular automata

A two-dimensional cellular automata has definite limitations for the representation of networks and of network change:

1. degree of a cell is constrained (max number of neighbors);
2. a limit on the maximum number of neighbors of a cell that are **unconnected** to each other (*Star* pattern);
3. the number of cells all of whom are connected to one another (a clique) (*Square* pattern);
4. actors will tend to acquire and lose sets of connections simultaneously when they change location in a network (strong tendency toward transitivity).

However, a moderate degree of transitivity may be more realistic than the assumption of complete independence in a computer simulation.

Cellular automata IV: multidimensional cellular automata

The limitations in the 2D cellular automata can be removed by increasing the number of dimensions. E.g., for a five dimensions, a cell can have hundreds of neighbors. The degree of transitivity decreases when the number of dimensions increases.

But if the number of dimensions exceeds 3, the cellular automata **cannot** produce images that are easy to visualize and understand.

$\Longrightarrow$ By increasing the number of dimensions any network can be represented by cellular automata.

The *Core*

The *core* is the fundamental solution concept for cooperative games. The core is based on the assumption that no subset of players should accept any less than their characteristic value - what they can guarantee themselves regardless of the actions of those not in their subset.

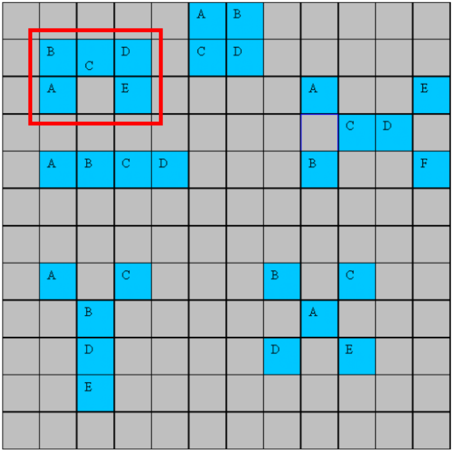
The *Core* II

Rules in a repeated network exchange game when only outcomes in the core are stable:

1. Actors who are excluded from an exchange raise their offers to others in the next game.
2. Actors who are included in an exchange make offers that allow them an unchanged profit.
3. All offers made by actors to others are equal in value (to themselves).
4. An actor leaves a current partner if and only if he receives a strictly superior offer from another.

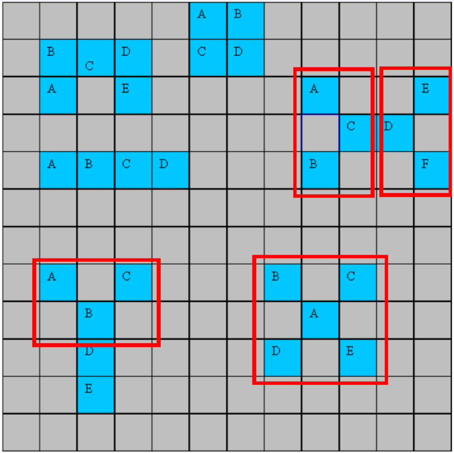
Types of power in networks: coreless components

Coreless components: It is possible that some pairs of actors are better off by trading with each other than with their current partners. $\Longrightarrow$ No exchange pattern will be stable.



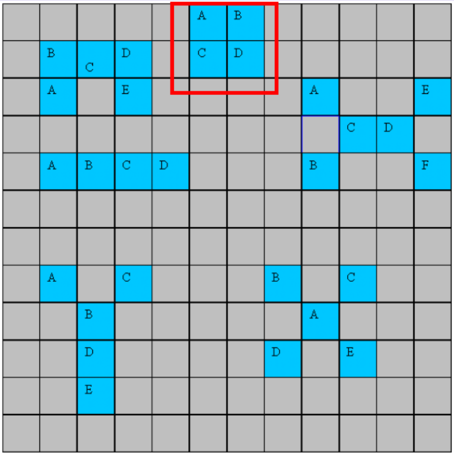
Types of power in networks II: strong power components

Strong power components: There is a unique solution. Some positions enjoy very high (complete) power at the expense of other positions.



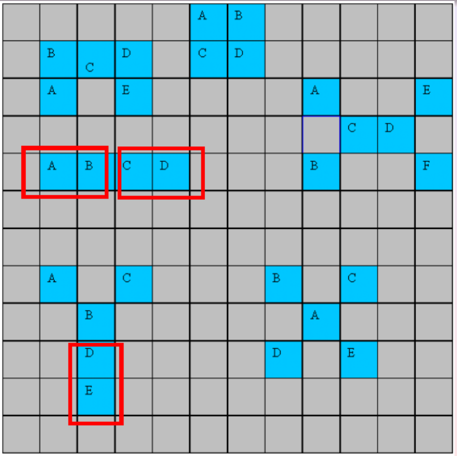
Types of power in networks III: equal power components

Equal power components:
There is a unique solution. All the parties have the same power.



Types of power in networks IV: indeterminate power components

Indeterminate power components:
There is an infinite number of solutions. None of the actors has a strong power but some small differences in power due to relations between components may exist.



Simulations' design

1. The simulated actors can change their network positions.
2. Actors are assumed to follow a very simple win-stay/lose-change strategy with respect to movement. Actors do not change their position if they earn more than a certain minimum.
3. Actors whose earnings fall below the minimum randomly pick a neighboring square, which they move to if it is unoccupied.
4. This actor does not select the position to which he moves on the basis of its worth; he moves blindly and randomly, quite possibly to a worse position. This is consistent with the assumption that the network of exchange opportunities is a consequence of the limited knowledge of the participants.

Conclusions

1. In networks with two complementary categories of unequal size, the members of the larger category remain weak. In other types of networks the results are approximately equal power.
2. Only networks with high degrees of power imbalance are unstable. There are three forms for stable networks: equal power, indeterminate power, and coreless.
3. Among non-bipartite networks, the outcome depends on whether there are an even or odd number of actors. With an even number of actors the outcome is **indeterminate** or **equal power components**. Networks with an odd number of actors evolve into **coreless** networks. Bipartite networks with equal numbers in the two categories evolve into **indeterminate** networks.

Comments & critique

Overall, it is interesting paper.

Possible extensions, comments:

1. How do results depend on the assumptions of the simulations?
2. What is the impact of transitivity on results if any?
3. The results of simulations (Figure 6) do not look realistic (earnings of A and C at the starting position are equal) and robust (the difference in earnings at the beginning and at the end of simulations is small).