The artificial world of the Pardus game: First lessons

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Venice, April 7th, 2011
INSITE Meeting
Establishing a socio-economic laboratory

• Establish a socio-economic laboratory for socio-economic behavior, behavioral economics, ...

• Evolving, multirelational organisation of human society

• Applications: Social balance, Weak Ties, Triadic Closure

• Massive multiplayer online game
Computational social science

Small-scale questionnaire-based

Large-scale datasets from electronic media (mobile phone, email, Facebook, ...)

Dynamics and organization of large social systems

Onnela et al., PNAS 104, 7332 (2007)
Establishing a socio-economic laboratory

Dynamics and organization of specific aspects of large social systems

Can we do better?

Socio-economic laboratories of whole human societies
Massive multiplayer online games

www.pardus.at

Players live an alternative life, in a virtual universe interacting with many others

- 375,000 registered players
- 15,000 active players
- Online since 2004

Szell and Thurner, Social Networks 32, 313-329 (2010)
The framework of the game

• Economic life
  Trade, produce, make profit
  Spend money on ships, ...

• Social life
  Chat, forum, make friends
  Alliance diplomacy

• Exploratory life (“Science”)
  Universe and lifeforms

no rules, no goals
Innovation 1: In-World

Emergence of complex social behavior

- Hierarchical groups
- Cartels, banks
- Experiments: “Communism”
- Political parties
- Organized attacks + wars over territory, resources, ...
Innovation 2: Out-World
Innovation 3: Player - Developer

Players
Feature request forum
“Pray to god”

Developers
New game feature
“God creates”
Innovation 4: “Science”

I'd prefer it if someone would peer-review my work.

---

All my helpers have stopped black-marketing data.

**Anyone black-marketing drugs, I would appreciate a PM if you're willing to log all your trades. It's pretty simple 😊**

In particular, I'd like to have someone with any amount of sneakiness and/or haggling, and also non-TSS members.

Additionally, I'd prefer it if someone would peer-review one item in my work: I derived a formula that should compute the average number of illegal trades that can occur before the black market closes, involving traps and bribes, given the percent chance that the BM stays open.

I'll outline the method I used, to make it simpler to verify:

1. I used a special-case discrete negative binomial distribution \( (r=1) \) to represent the number of trades, "\( k \)”, before it closes once (hence \( r=1 \)), if "\( p \)" is the probability of the BM staying open:
   \[
   f(k) = (1 - p) \cdot p^k
   \]
   so as an example, if the BM stays open for 60% of the trades, the chance that the 2nd trade will be the last trade before the BM closes is \( 0.4^2 \cdot 0.6^2 \), or about 14.4%. But this only gave me the probability that for trial number "\( k \)”, the BM would close on the following trade.

2. To calculate the average number of trades that occur before the BM closes, I would have to sum all the probabilities starting from trade zero (since the BM can shut down on the first trade) until they add up to 50%.
   That will be the average number of trades before the BM closes since 50% of the time it will close before that, and 50% of the time it will close after that. This then, represents the summation, and "\( s \)” represents the trade *before* the BM closes:
   \[
   (1 - p) \cdot \sum_{k=0}^{s} p^k = 0.50
   \]

3. But I want a closed-form equation that I don’t have to iteratively sum every time I log more data. This is a variation on the first equation here that I used to remove the summation for a closed-form solution:
   \[
   \sum_{k=m}^{s} p^k = \frac{p^m - p^{s+1}}{1 - p}
   \]

4. And finally, substituting that for the summation (the "1-p" terms cancel), simplifying, and solving for "\( s \)" yielded:
   \[
   s = \frac{\ln 0.5}{\ln p} - 1
   \]
   Again, "\( s \)” is the average number of trades over many illegal BM trades you can expect before the BM closes on the *next* trade. But it’s more useful to know on which trade the BM can be expected to shutdown since when the BM shuts down, the drugs are still sold for money successfully.

To find out on which trade the BM will most often shut down, just remove the "- 1" at the end. Plug in the chance that the BM will stay open for "\( p \)”, and solve for "\( s \)” in this equation:
Data available

- All actions by all players
- Over 2000 days, with timestamp
- Ongoing generation of new data
- Unobtrusive

3 Universes
First lessons: Quantitative Sociology

• Show usefulness of online game for research
• Establish validity of virtual environment
• Compare with existing “real world” studies
• Check classical sociological hypotheses
Six types of social networks

Directed one-to-one interactions

<table>
<thead>
<tr>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friendship</td>
<td>Enmity</td>
</tr>
<tr>
<td>Communication</td>
<td>Attack</td>
</tr>
<tr>
<td>Trade</td>
<td>Bounty</td>
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Part I  MULTIPLEXITY
The importance of being multiplex

Usually:
Nature of relations unavailable
The importance of being multiplex

Here:
Nature of relations available

Multiplex network

- Girlfriend (purple)
- Colleagues (green)
- Family (blue)
- Friends (orange)
Structural differences between positive and negative interactions

Reciprocity

If I * you, do you * me?

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<td>$N$</td>
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</tr>
<tr>
<td>$r$</td>
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<td>0.28</td>
</tr>
<tr>
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</tr>
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<td>0.88</td>
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Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)
Structural differences between positive and negative interactions

If I * others, do they * each other?

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**YES**

Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)
Structural differences between positive and negative interactions

In/Out degree correlation

If I * few/many others, do few/many others * me?

|          | Positive |          |  |  |          |  |  |          |  |  |
|----------|----------|----------|  |  |----------|  |  |----------|  |  |
|          | Friends  | PMs      | Trades       |  |  | Enemies  | Attacks | Bounties |
| **N**    | 4,313    | 5,877    | 18,589       |  |  | 2,906    | 7,992   | 2,980    |
| **r**    | 0.68     | 0.84     | 0.57         |  |  | 0.11     | 0.13    | 0.20     |
| **C**    | 0.25     | 0.28     | 0.43         |  |  | 0.03     | 0.06    | 0.01     |
| **C/C^rand** | 109.52 | 45.71    | 131.95       |  |  | 6.13     | 37.27   | 13.88    |
| **ρ(k^in, k^out)** | 0.88   | 0.98     | 0.93         |  |  | 0.11     | 0.64    | 0.31     |

**YES**

Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)
Structural differences between positive and negative interactions

Being marked as enemy
Marking somebody as enemy
Attacking somebody
Being attacked

Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)
Structural differences between positive and negative interactions

Conflict leads to fat tails

Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)
The importance of being multiplex

Ignorance of relation types

Loss of essential information!

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Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)
Network-network interactions

Description of co-existence of links

• Link overlap (Jaccard coefficient)

Low

High

Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)
Network-network interactions

Description of co-existence of links

- Link overlap (Jaccard coefficient)
- Degree correlation

Low

High

Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)
Network-network interactions

Different roles in different networks

Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)
Application: Social balance theory

Social balance: Theory about balance and cognitive dissonance in social networks

Multiplex network of friends (+) and enemies (-)

Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)
Application: Social balance theory

Multiplex network of friends (+) and enemies (-)

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<th>U</th>
<th>B</th>
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<tr>
<td>Weak formulation of balance</td>
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<td>U</td>
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<thead>
<tr>
<th>$N_\Delta$</th>
<th>26,329</th>
<th>4,428</th>
<th>39,519</th>
<th>8,032</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{\Delta,r}$</td>
<td>10,608</td>
<td>30,145</td>
<td>28,545</td>
<td>9,009</td>
</tr>
<tr>
<td>$\tilde{\gamma}$</td>
<td>71</td>
<td>-112</td>
<td>47</td>
<td>-5</td>
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Evidence for overrepresentation of balanced triads
Evidence for underrepresentation of unbalanced triads

Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)
Application: Social balance theory

Multiplex network of friends (+) and enemies (-)

Evidence for overrepresentation of balanced triads
Evidence for underrepresentation of unbalanced triads

Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)
Application: Weak ties hypothesis

“Communities are connected by weak ties”

Granovetter, Amer. Journal of Soc. 87, 27 (1973)
Application: Weak ties hypothesis

Preliminary assumption

“The degree of overlap of two individual’s friendship networks varies directly with the strength of their tie to one another”

\[ O_{ij} := \frac{n_{ij}}{(k_i - 1) + (k_j - 1) - n_{ij}} \]

“strength” \( \equiv w \) PMs exchanged

\[ O \sim \sqrt[3]{w} \]

Szell and Thurner, Social Networks 32, 313-329 (2010)
Granovetter, Amer. Journal of Soc. 87, 27 (1973)
Application: Weak ties hypothesis

“bridges are weak ties”

$$b_{ij} := \sum_{m \in \mathcal{N}} \sum_{n \in \mathcal{N} \setminus \{m\}} \frac{\rho_{mn}(l_{ij})}{\rho_{mn}}$$

Similar in mobile phone networks

Onnela et al, New Journal of Phys. 9, 6 (2007)
Szell and Thurner, Social Networks 32, 313-329 (2010)
Granovetter, Amer. Journal of Soc. 87, 27 (1973)
Part II  NETWORK EVOLUTION
Preferential attachment

Does network growth follow PA?

If yes:

1) Linking probability $P(k) \sim k^\alpha$, $\alpha = 1$

2) Degree distribution follows power law

Barabási and Albert, Science 286, 509 (1999)
Preferential attachment

1) Linking probability \( P(k) \sim k^\alpha, \quad \alpha = 1 \)

Friends

Enemies
2) Degree distribution follows power law

Friends ➡️ Enemies

→ Cannot apply Preferential Attachment naively!
Densification

Average degrees grow

Diameters shrink

Leskovec et al, ACM TKDD 1 (2007)
Szell and Thurner, Social Networks 32, 313-329 (2010)
Accelerated Growth

Dorogovtsev and Mendes, PRE 63, 25101 (2001)
Bettencourt et al, PNAS 104, 7301 (2007)
Szell and Thurner, Social Networks 32, 313-329 (2010)
Application: Triadic Closure

Directed triad classes
Application: Triadic Closure

More generally

Expect over-representation of complete triads in friend networks

Granovetter, Amer. Journal of Soc. 87, 27 (1973)
Triad significance profile = Statistical significances of triad classes in the network compared to random networks

Indicates triadic closure

Szell and Thurner, Social Networks 32, 313-329 (2010)
Application: Triadic Closure

Measure all transitions between triad classes over time interval

\( \mathbb{K} \)

- Explicit quantitative evidence for triadic closure
- Provide transition probabilities for modeling

Szell and Thurner, Social Networks 32, 313-329 (2010)
Application: Signed Triadic Closure

Wedge

Balanced

Unbalanced

Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)
Application: Signed Triadic Closure

Balanced closure dominates!

Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)
Application: Signed Triadic Closure

Wedge

Enemy of enemy irrelevant

Szell, Lambiotte and Thurner, PNAS 107, 13636-13641 (2010)
Summary

• Establish a large-scale socio-economic laboratory
• Structural differences between pos. and neg. ties
• Multiplex Network: Social balance, Weak ties hyp.
• Network Evolution: Triadic Closure
Contact

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Articles
