# The Structural Dimension of Cooperation

## Cooperation Networks as Cohesive Small Worlds

Jordi Torrents

University of Barcelona

December 11, 2016

# Research Question

The last half of twentieth century has witnessed a key shift in the production process of knowledge.

## Well established empirical fact about Cooperation

Wuchty, Jones, and Uzzi (2007) show that until 1950s the likelihood that an important —ie wildly cited— paper or invention was developed by a single author was bigger than it was developed by a team. But this trend has experimented a shift in the last four decades. The rising importance of collective research and cooperation is illustrated by the fact that top cited papers are mostly created by teams in 2000s.

## Research question

How does large scale cooperation work in knowledge intensive and technically complex production processes developed in new organizational environments, such as Free and Open Source Software projects, where loosely coupled individuals that rarely meet face to face have to coordinate through internet in order to produce world class software products.

# Theoretical Approaches to Cooperation

## Macro level approach

Cooperation as a macro level phenomenon in which the center of analysis is the collective or group (Marx, 1990; Adler and Heckscher, 2006; Adler, 2015).

- Focus on large organizations and groups: Collaborative Communities
  - Shared values and goals
  - Generalized trust
  - Authority forms

## Micro level approach

Cooperation as a micro level phenomenon in which the center of analysis is the dyad (Axelrod and Hamilton, 1981; Watts, 1999; Eguíluz et al., 2005).

- Reductionist approach: Cooperation as an atomic process.
  - Strategic dyadic interactions.
  - Agent-based models.
  - Payoffs of different strategies.

## A meso level approach to Cooperation

Focus on Cooperation networks: patterns of relations that direct producers establish in the production process.

- Structural approach, that is, a network approach.
  - Sub-groups that are more connected internally than with the rest of the network.
  - Longitudinal analysis of the formation and dissolution of these groups.
  - Key mechanisms to explain and understand large scale cooperation.

# Collaborative Communities as a macro approach

A new form of community, qualitatively different from the traditional *Gemeinschaft* and the modern *Gesellschaft* (Tönnies, 1974)

## Collaborative Communities (Adler and Heckscher, 2006)

Novel organizational form —both inside and outside large capitalist corporations— strongly grounded on large scale cooperation which defy the traditional dichotomy between **hierarchy** and **market** as coordinating mechanisms.

- Generalized trust
- Conscius cooperation and High individual interdependence
- Shared values and Value-rational basis for legitimate authority

## Network (structural) model for Collaborative Communities

Cohesive Small World Based on the well known Small World and Structural Cohesion Models. Which structural conditions enable trust and value congruence?

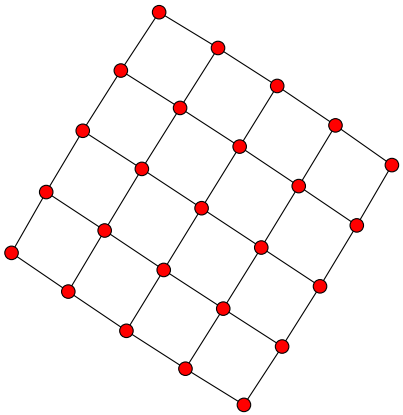
- Small Worlds: Local clusters connected by shortest paths.
- Structural Cohesion: Increasingly cohesive groups nested inside each other.

# Cohesive Small World

## Pure Structural Cohesion

- Robust to node removal
- Not necessary short average distance
- Not necessary local clustering

Pure Structural Cohesion

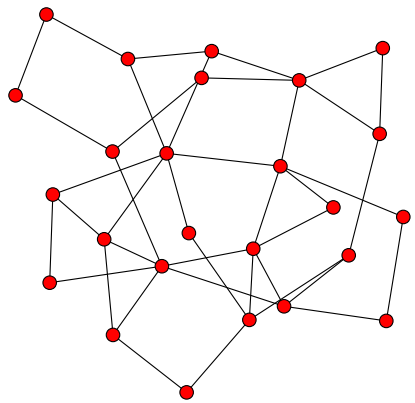


n=25, m=40, CC=0.00, APL=3.33, SWI=0.00, nodes in GBC=100%

## Cohesive Small World

- Intersection of the two models
- Short average distance
- High local cluster coefficient
- Robust to node removal

Cohesive Small World

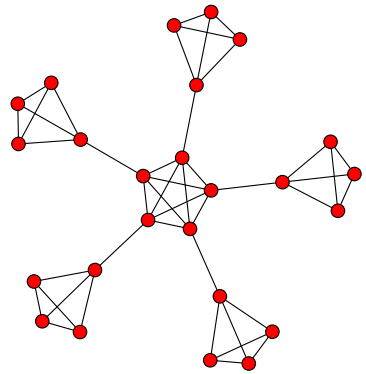


n=25, m=40, CC=0.19, APL=2.67, SWI=1.57, nodes in GBC=100%

## Pure Small World

- Short average distance
- High local cluster coefficient
- Not necessary robust to node removal

Pure Small World



n=25, m=45, CC=0.82, APL=3.38, SWI=4.23, nodes in GBC=20%

# The structural cohesion model

The structural cohesion model (White and Harary, 2001; Moody and White, 2003) is based on two mathematically equivalent definitions of cohesion.

**Precise definition of group cohesion based on node connectivity**

- a group's structural cohesion is equal to the minimum number of actors who, if removed from the group, would disconnect the group.
- a group's structural cohesion is equal to the minimum number of node independent paths linking each pair of actors in the group.

This equivalence relation has a deep sociological meaning because it allows to define structural cohesion in terms of:

- the difficulty to pull a group apart by removing actors.
- multiple relations between actors that keep a group together.

# Measures of structural cohesion

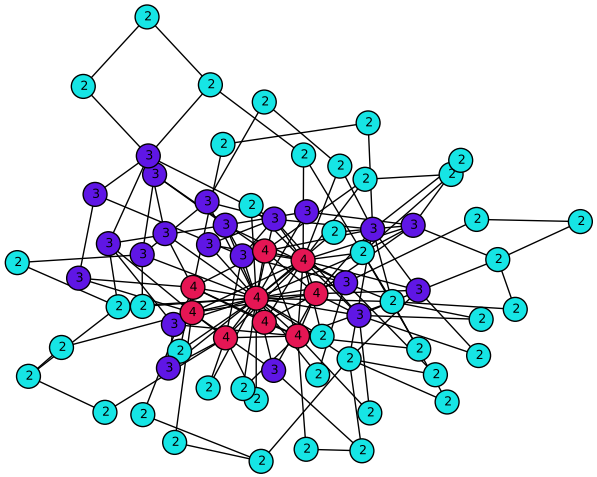
## Node connectivity $\kappa(G)$

**Local** given two nodes $u$ and $v$, $\kappa_G(u, v)$ is the minimum number of nodes that must be removed to destroy all paths that join $u$ and $v$.

**Global** the minimum number of nodes that must be removed in order to disconnect a graph $G$.

## $k$-components

A $k$-component is a maximal subgraph that has, at least, node connectivity $k$: we need to remove at least $k$ nodes to break it into more components.



# Free and Open Source Projects: Debian and Python

Free Software, broadly defined, is computer software that allows users to run, copy, distribute, study, change and improve it.

## The Debian Project: 1999-2012

- A free Operating System
- 392 developers in 1999, 1435 in 2012
- 2876 programs in 1999, 10469 in 2012
- Widely used in servers (google), desktops (Ubuntu) and embedded devices (raspberry pi)

## The Python project: 1999-2014

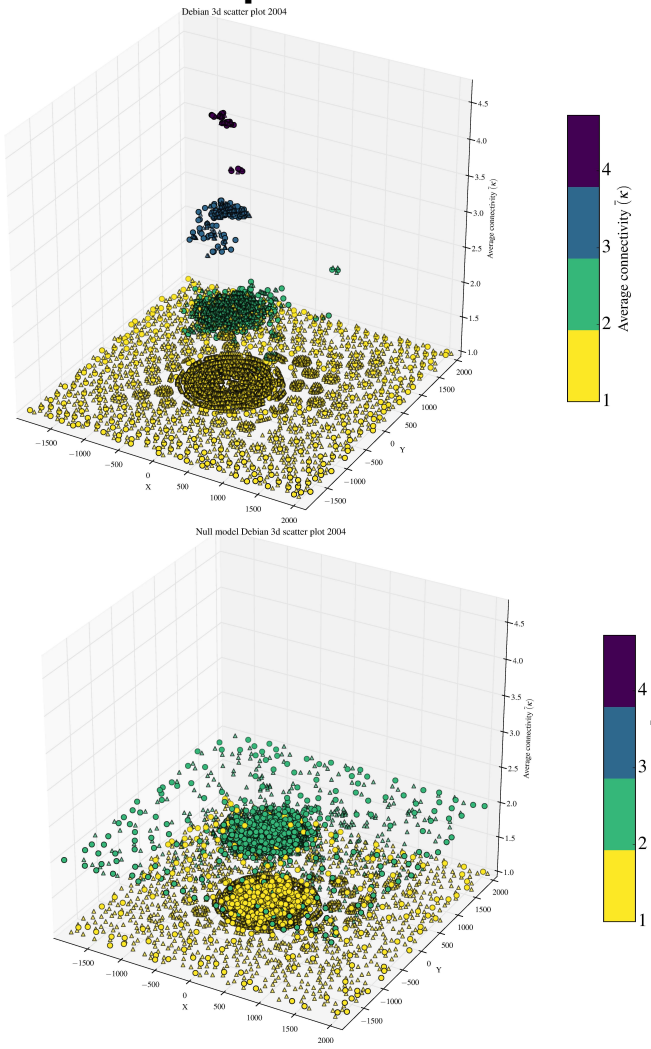
- A free Programming Language
- 9 developers in 1999, 62 in 2014
- 1137 files in 1999, 2134 in 2014
- Widely used in web development (reddit, youtube) and scientific computing

## Building and Analyzing Cooperation Networks

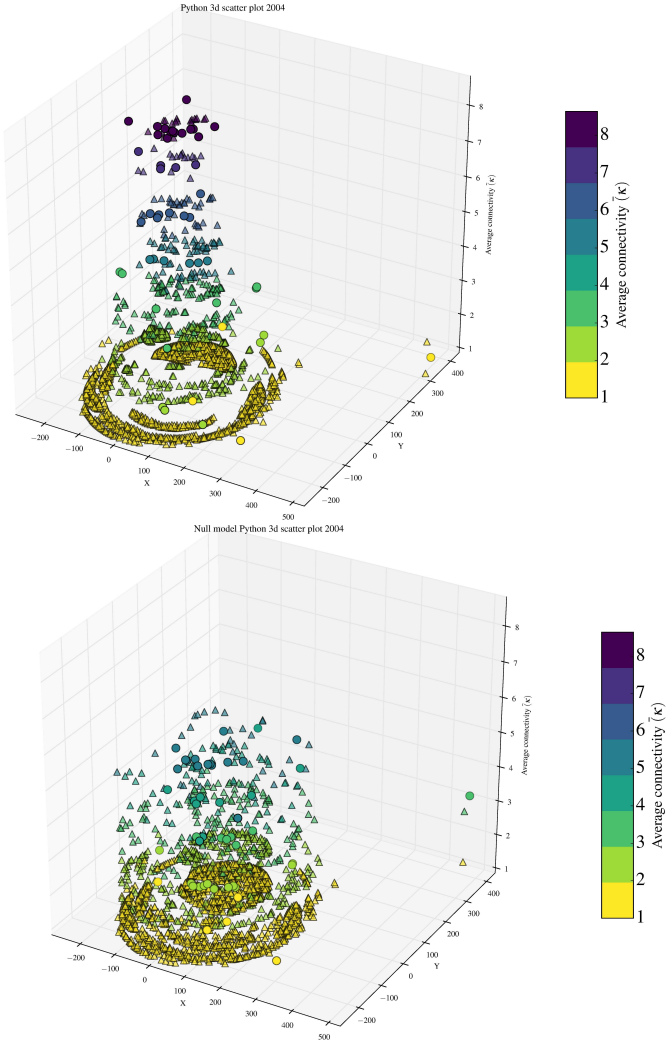
- Cooperation networks are bipartite or two mode (both developers and programs)
- A developer is linked to the package or source code file that she works on
- Structural Cohesion Analysis: $\kappa$-components as sub-groups
- Small World Analysis: Average Path Length and Clustering Coefficient

# Structural Cohesion Analysis

## Debian Cooperation Network 2004



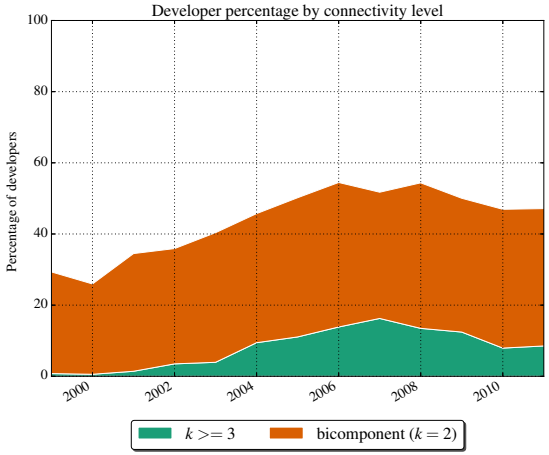

## Python Cooperation Network 2004

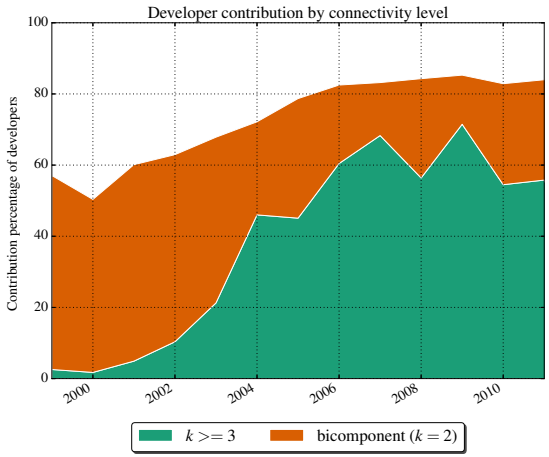


# Iron law of the Oligarchy or an Open Elite?

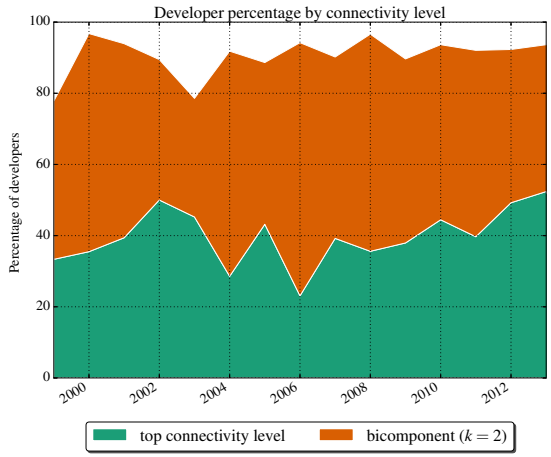
The literature on FOSS, especially from software engineering and computer science, have stressed that only a small fraction of the developers is doing most of the work.

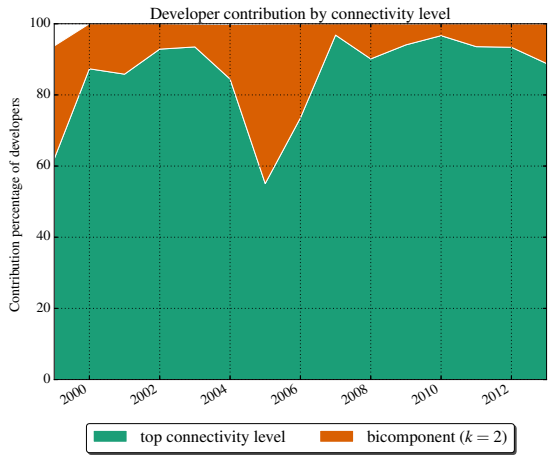
## Debian Contributions



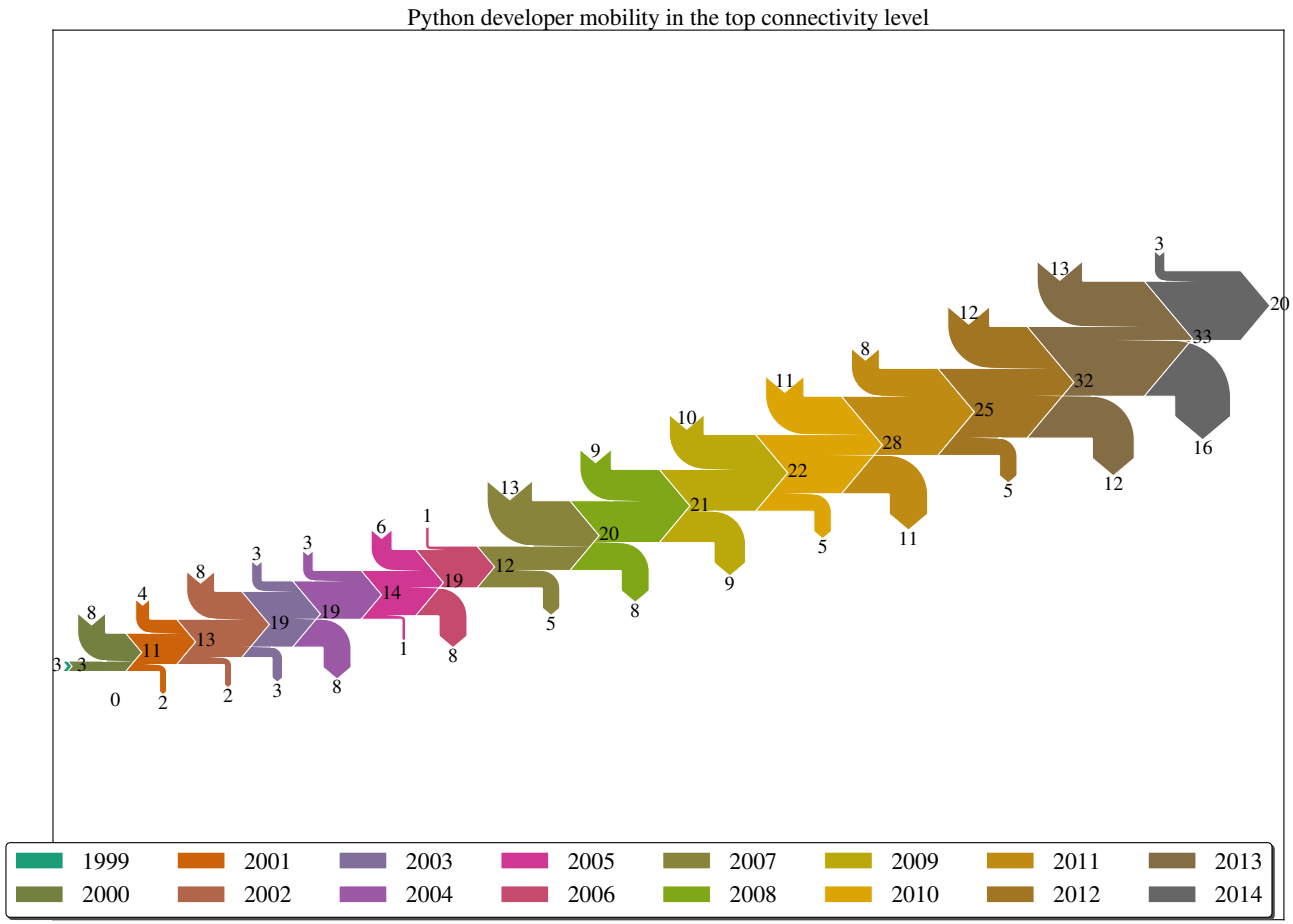

## Python Contributions



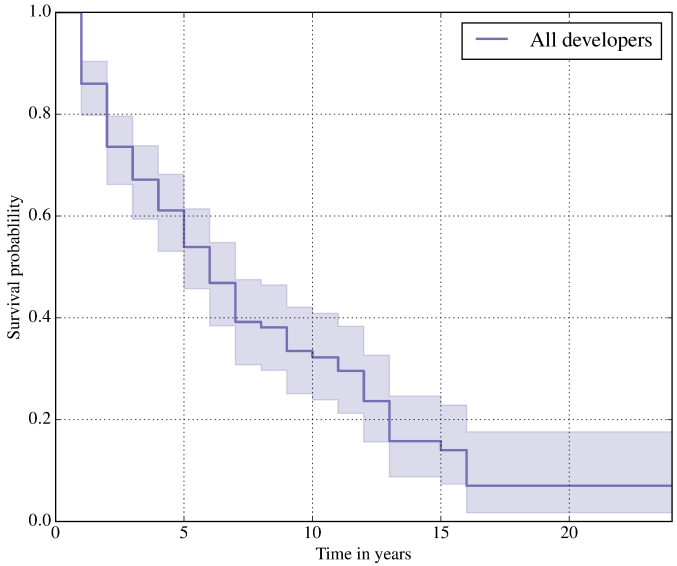



# Cooperation Networks' Connectiviy Hierarchies as Open Elites

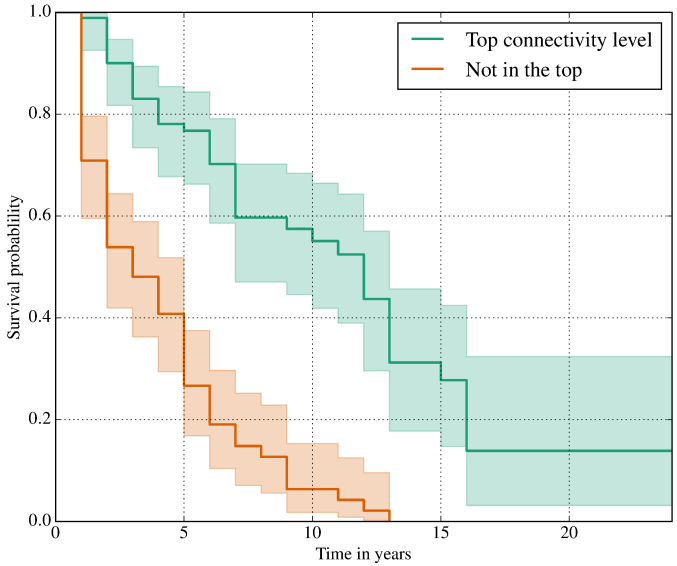
Sankey diagram of Python developer mobility in the top connectivity level.



# Modeling robustness as median active live of individuals in the project




(a) Survival Function for all developers




(b) Survival Function for developers in the top connectivity level

Figure: Estimation of the survival function using the Kaplan-Meier estimate. The median survival time of a developer in the community, defined as the point in time where on average half of the population has abandoned the community, is 6 years if I consider all developers (left). But if I consider separately the developers in the top level of the connectivity hierarchy (right), their median survival time is 12 years; but only 3 years for the developers that are not on the top of the connectivity hierarchy.

# References

Adler, P. and C. Heckscher (2006). *The Firm as a Collaborative Community: Reconstructing Trust in the Knowledge Economy*. Oxford University Press, Oxford, UK.

Adler, P. S. (2015). Community and innovation: from tönnies to marx. *Organization Studies 36*(4), 445–471.

Axelrod, R. and W. Hamilton (1981). The evolution of cooperation. *Science 211*(4489), 1390–1396.

Eguíluz, V., M. Zimmermann, C. Cela-Conde, and M. Miguel (2005). Cooperation and the Emergence of Role Differentiation in the Dynamics of Social Networks 1. *American journal of sociology 110*(4), 977–1008.

Marx, K. (1990). *Capital: a critique of political economy. Volume 1*. Penguin Books in association with New Left Review.

Moody, J. and D. White (2003). Social cohesion and embeddedness: A hierarchical conception of social groups. *American Sociological Review 68*(1), 103–28.

Tönnies, F. (1974). *Community and association:(Gemeinschaft und Gesellschaft)*. Taylor & Francis.

Watts, D. (1999). *Small Worlds: The Dynamics of Networks Between Order and Randomness*. Princeton University Press.

White, D. and F. Harary (2001). The cohesiveness of blocks in social networks: Node connectivity and conditional density. *Sociological Methodology*, 305–359.

Wuchty, S., B. Jones, and B. Uzzi (2007). The increasing dominance of teams in production of knowledge. *Science 316*(5827), 1036.