

Analyzing code contributions to the CPython project using NetworkX and Matplotlib

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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

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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.

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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.

Group Cohesion in the sociological literature

Central concept that has a long and illustrious history in sociology. Its use in most sociological research has been ambiguous at best (Moody and White, 2003):

- ① sloppy definitions of cohesion with lack of generality.
- ② grounded mostly in intuition and common sense.

Group cohesion (Doreian and Fararo, 1998) can be divided analytically into:

Ideational component based on the members' identification with a collectivity.

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The relational component of group cohesion has been the focus of Social Network Analysis.

Network theory measures used to define group cohesion

Classical measures cliques, clans, clubs, k -cores, lambda sets, ...

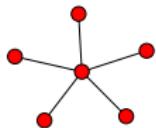
Community algorithms detect groups of nodes more densely connected among them than with the rest of the network.

Neither the classical approaches nor new developments in community analysis work well in empirical analysis of group cohesion.

Key properties that a cohesion measures should have

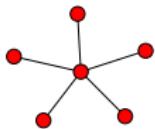
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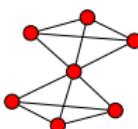
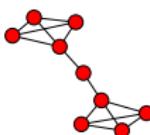


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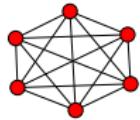
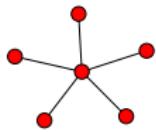


Overlap a cohesion measure should allow some actors to be part of more than one cohesive subgroup.

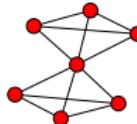
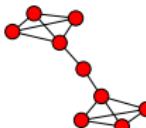


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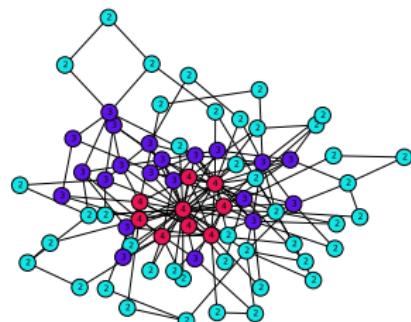
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Hierarchical highly cohesive subgroups are nested inside less cohesive ones.



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.

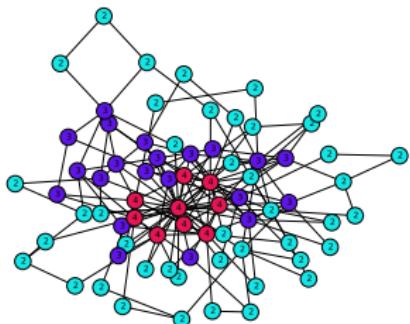
Components and k -components

Component

A *component* of a graph G is a maximal connected subgraph, which means that there is at least one path between any two nodes in that subgraph.

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.



- **Red Nodes** form a 4-component: we need to remove 4 nodes to disconnect it.
- **Purple Nodes** form a 3-component along with red nodes: we need to remove 3 nodes to disconnect it.
- **Blue Nodes** form a 2-component along with red and purple nodes: we need to remove 2 nodes to disconnect it.

Free and Open Source Projects: The CPython project

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

The CPython project: 1999-2014

- Reference implementation of the Python programming language
- Guido van Rossum started the development in 1991 as a personal project
- 9 developers in 1999, 62 in 2014
- 1137 source code files in 1999, 2134 in 2014

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Why analyze the CPython project?

- One of the most popular programming languages
- Widely used in web development and scientific computing
- Thus, a it's successful example of large scale cooperation
- We have detailed electronic records of source code contributions: mercurial repository.

Cooperation Networks and Null Models

My modeling strategy to capture the patterns of relations among developers is to focus on the actual contributions of each developer to the project.

Building Cooperation Networks

- Focus on the patterns of relations among developers in the productive process.
- Cooperation networks are bipartite or two mode; node sets are developers and source code files, and edges only link nodes from opposite sets.
- A developer is linked to the source code files that she works on. Each edge is weighted by the number of lines of source code added.
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Building Suitable Null models

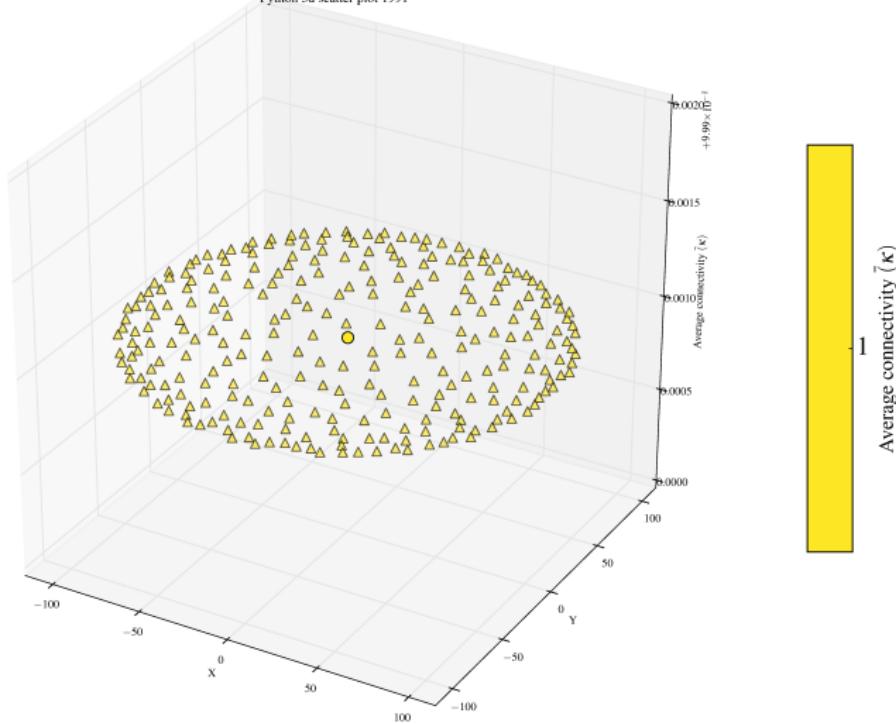
- We need to compare the statistical measures obtained from the actual networks with a suitable null model in order to assert that what we observe is not the result of pure chance.

Configuration Model assigns at random developers to source code files, maintaining the concrete skewed distribution of files by developer observed in the actual networks. That is, the degree distribution.

Graphical Representation of the Structural Cohesion Analysis

Python Cooperation Network 1991 (1 developer)

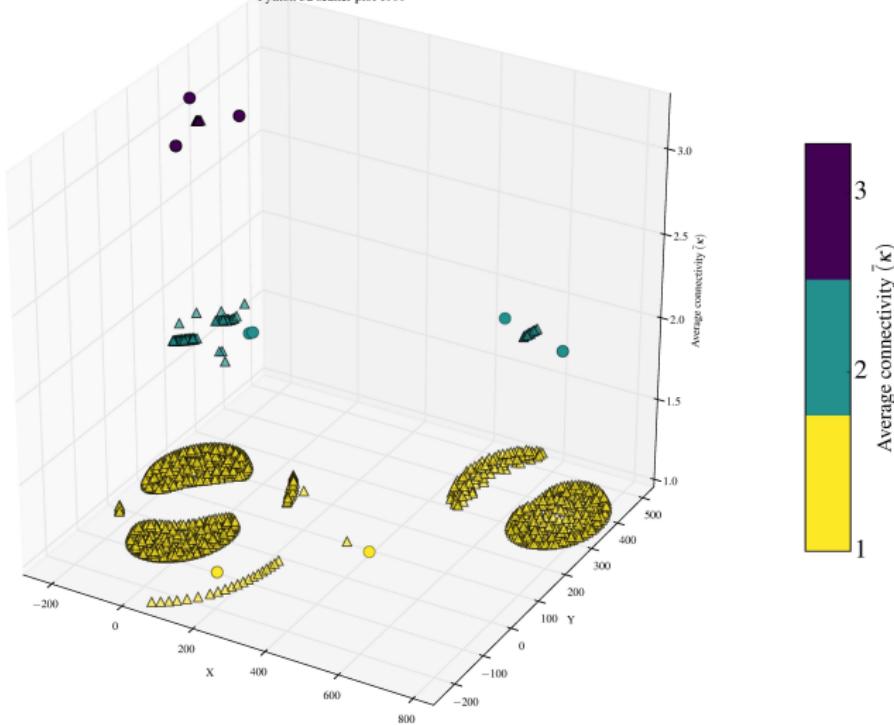
Python 3d scatter plot 1991



Graphical Representation of the Structural Cohesion Analysis

Python Cooperation Network 1999 (9 developers)

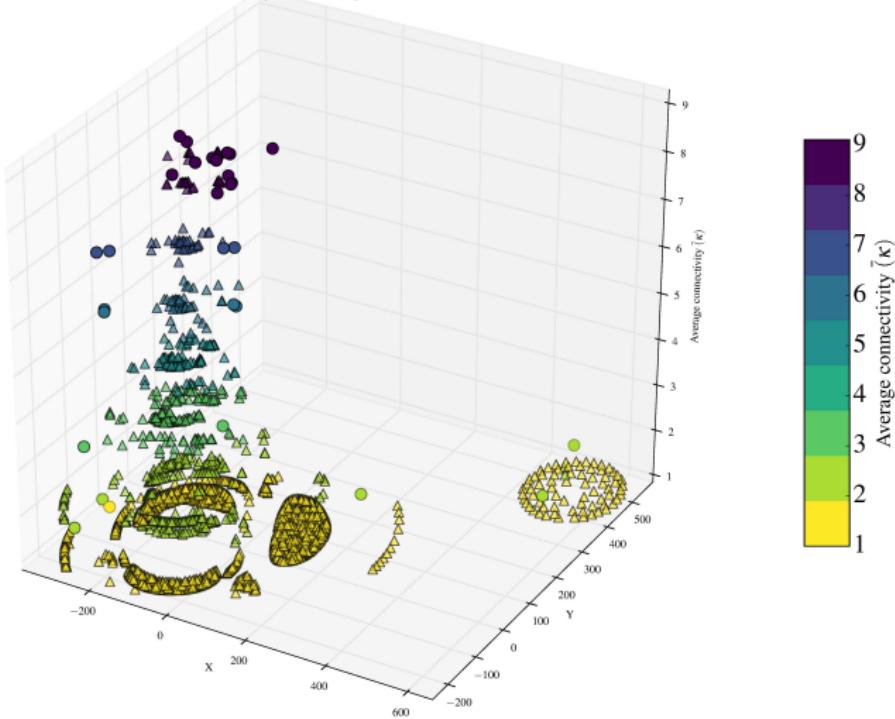
Python 3d scatter plot 1999



Graphical Representation of the Structural Cohesion Analysis

Python Cooperation Network 2000 (31 developers)

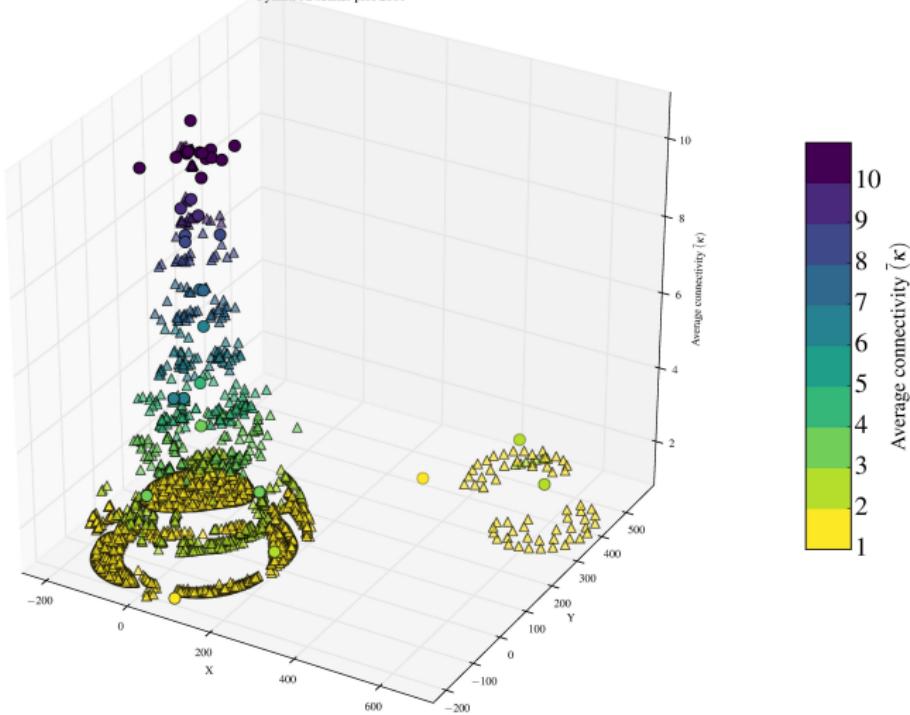
Python 3d scatter plot 2000



Graphical Representation of the Structural Cohesion Analysis

Python Cooperation Network 2001 (33 developers)

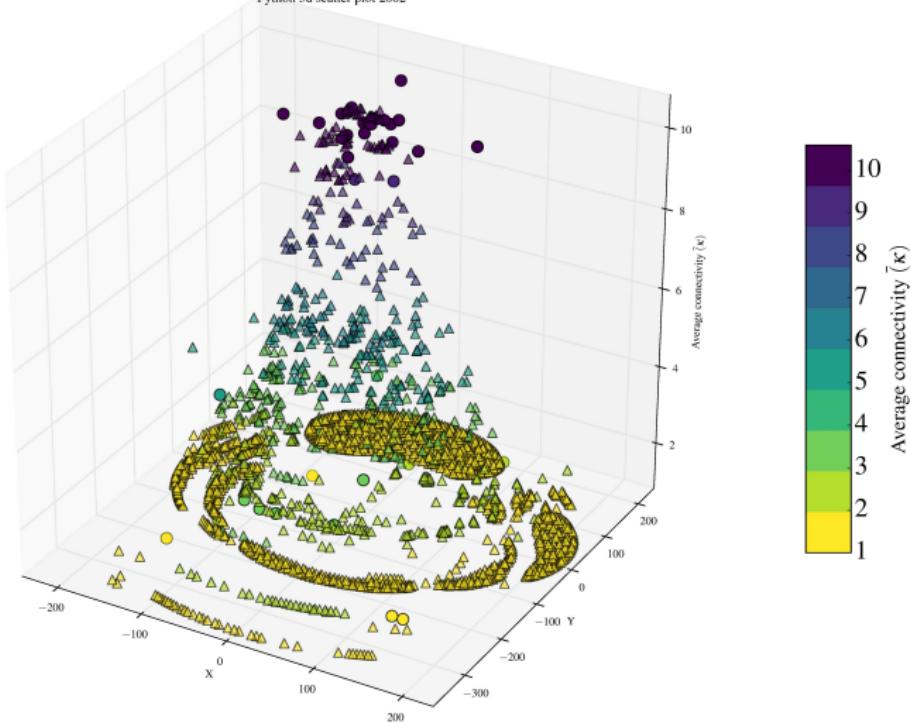
Python 3d scatter plot 2001



Graphical Representation of the Structural Cohesion Analysis

Python Cooperation Network 2002 (38 developers)

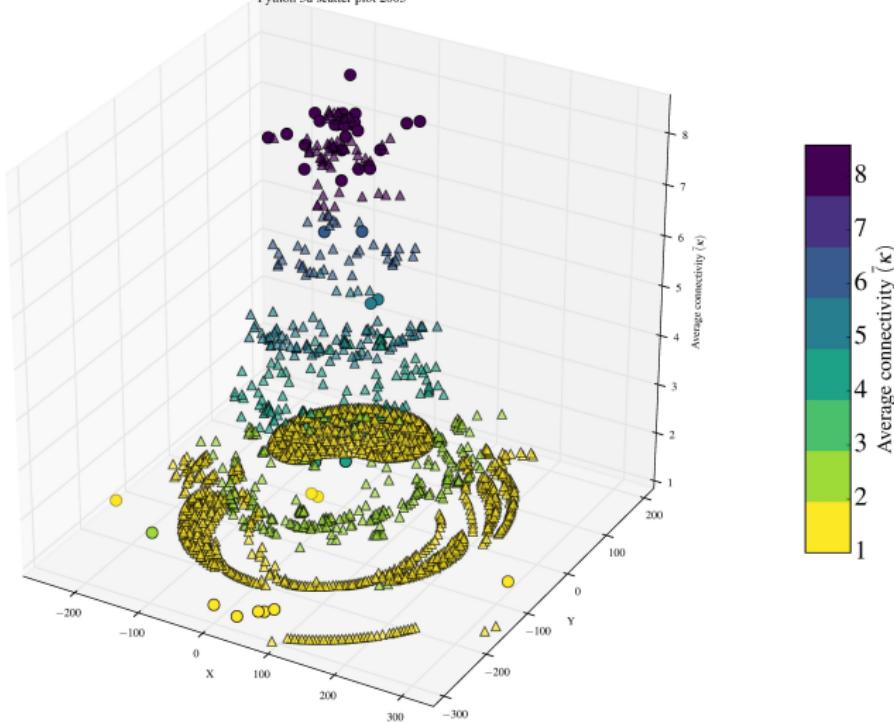
Python 3d scatter plot 2002



Graphical Representation of the Structural Cohesion Analysis

Python Cooperation Network 2003 (42 developers)

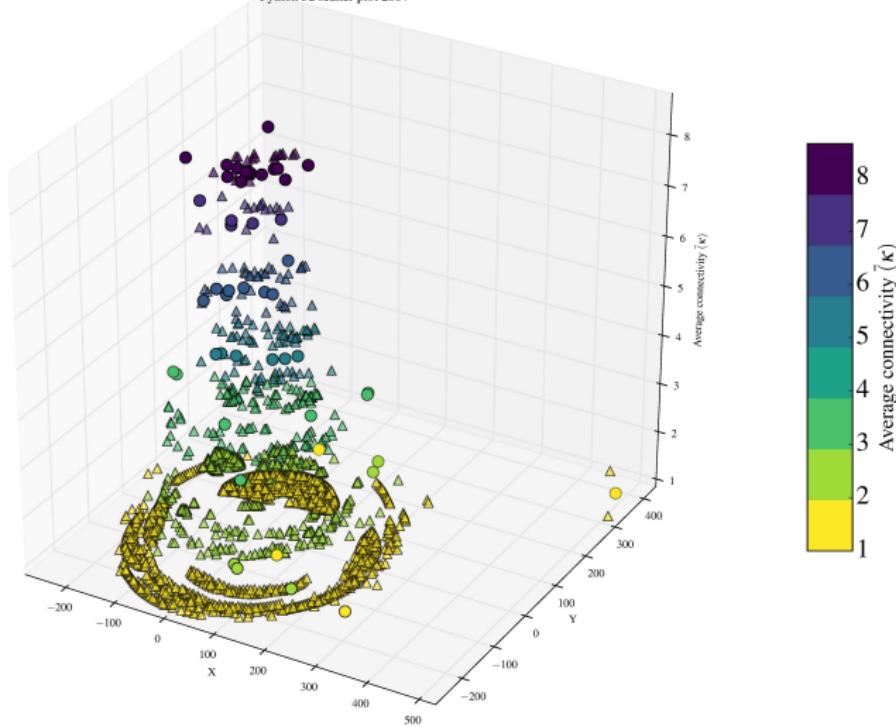
Python 3d scatter plot 2003



Graphical Representation of the Structural Cohesion Analysis

Python Cooperation Network 2004 (49 developers)

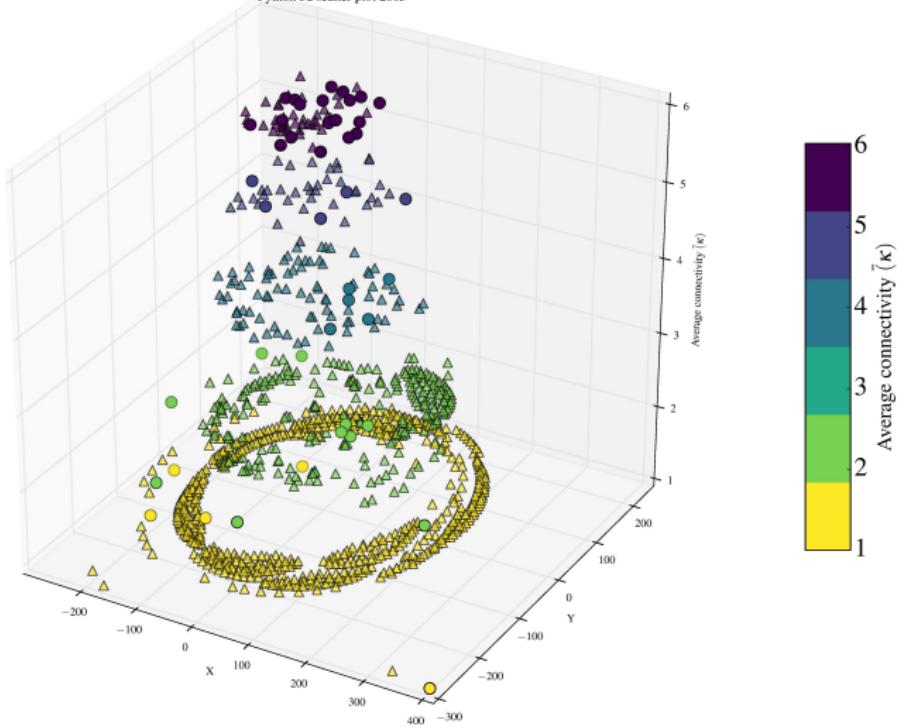
Python 3d scatter plot 2004



Graphical Representation of the Structural Cohesion Analysis

Python Cooperation Network 2005 (44 developers)

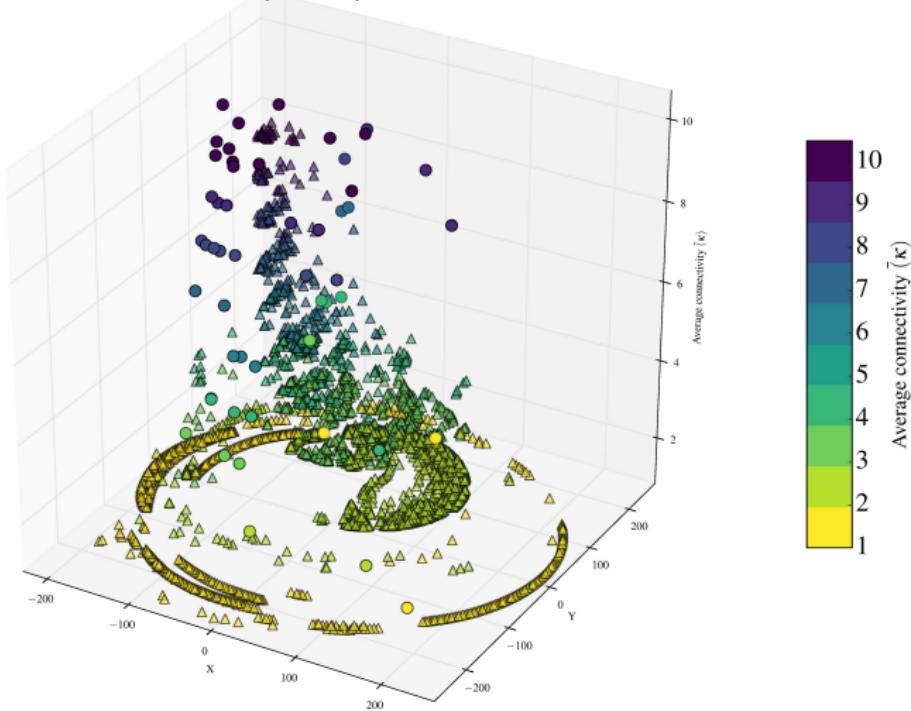
Python 3d scatter plot 2005



Graphical Representation of the Structural Cohesion Analysis

Python Cooperation Network 2006 (52 developers)

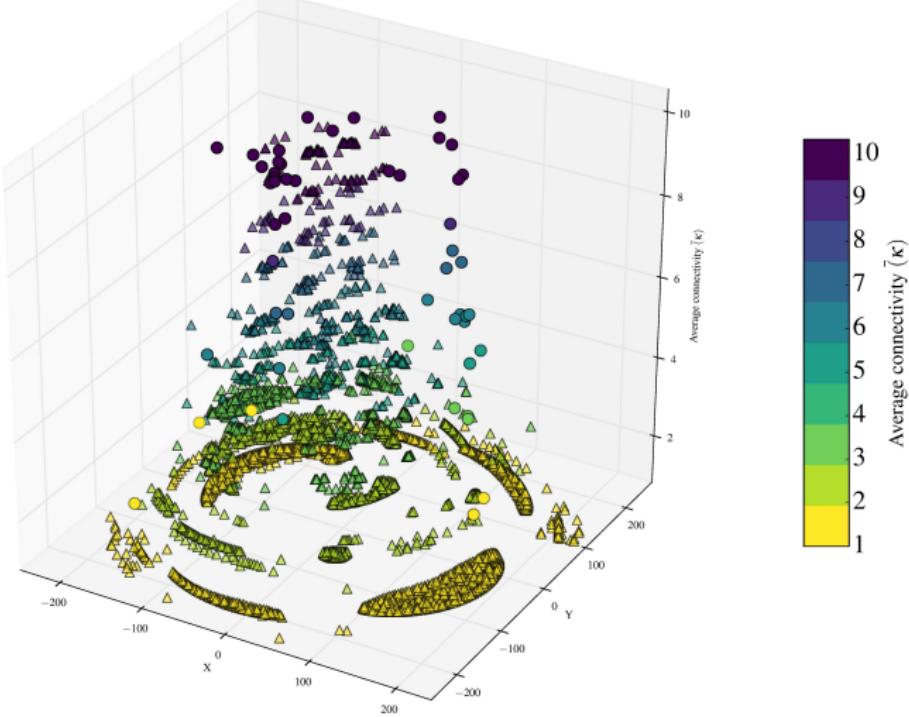
Python 3d scatter plot 2006



Graphical Representation of the Structural Cohesion Analysis

Python Cooperation Network 2007 (51 developers)

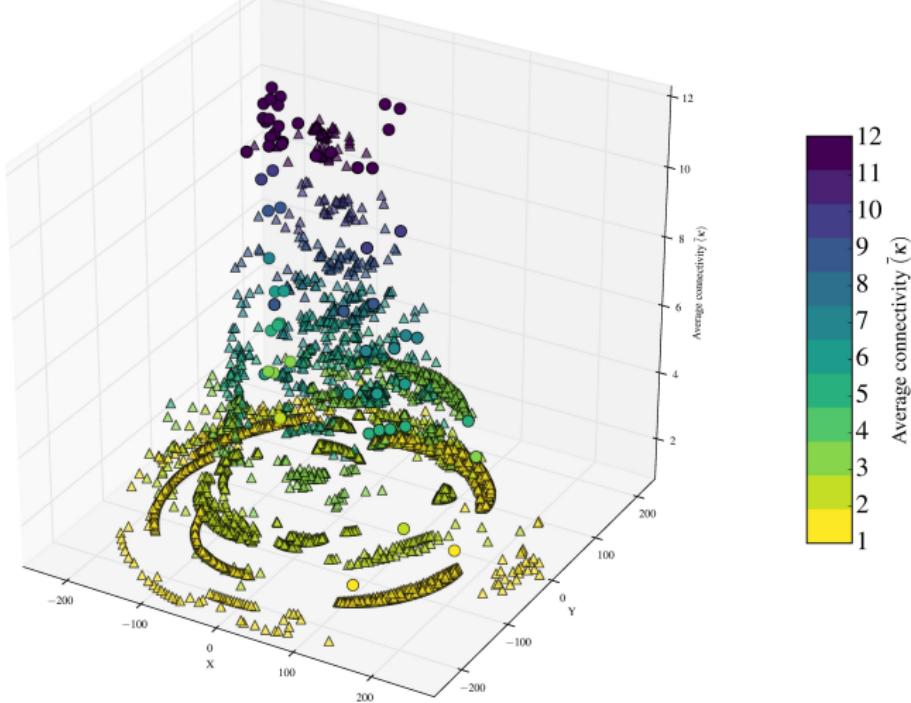
Python 3d scatter plot 2007



Graphical Representation of the Structural Cohesion Analysis

Python Cooperation Network 2008 (59 developers)

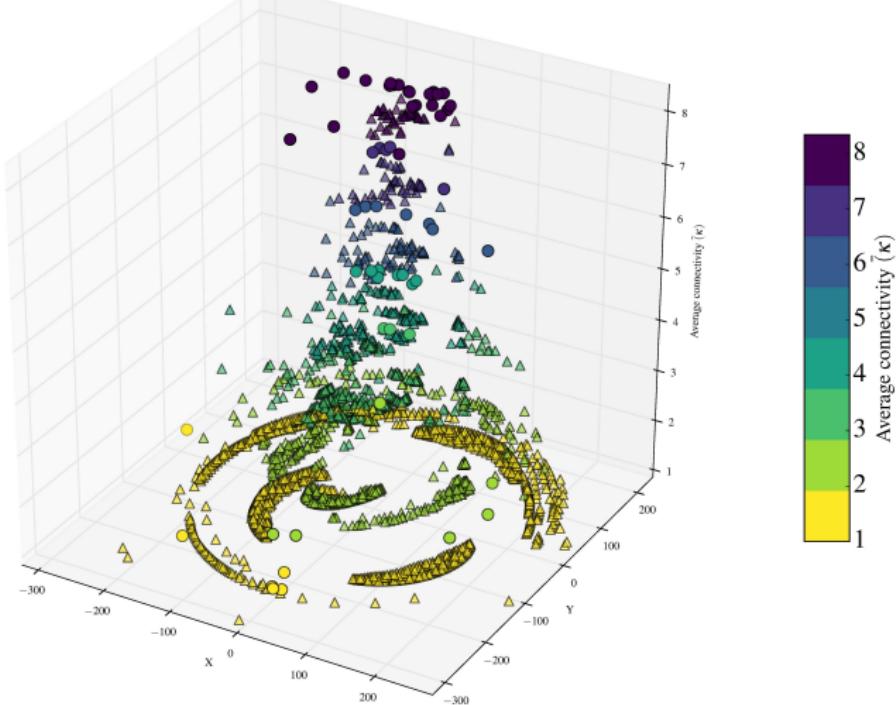
Python 3d scatter plot 2008



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Python Cooperation Network 2009 (58 developers)

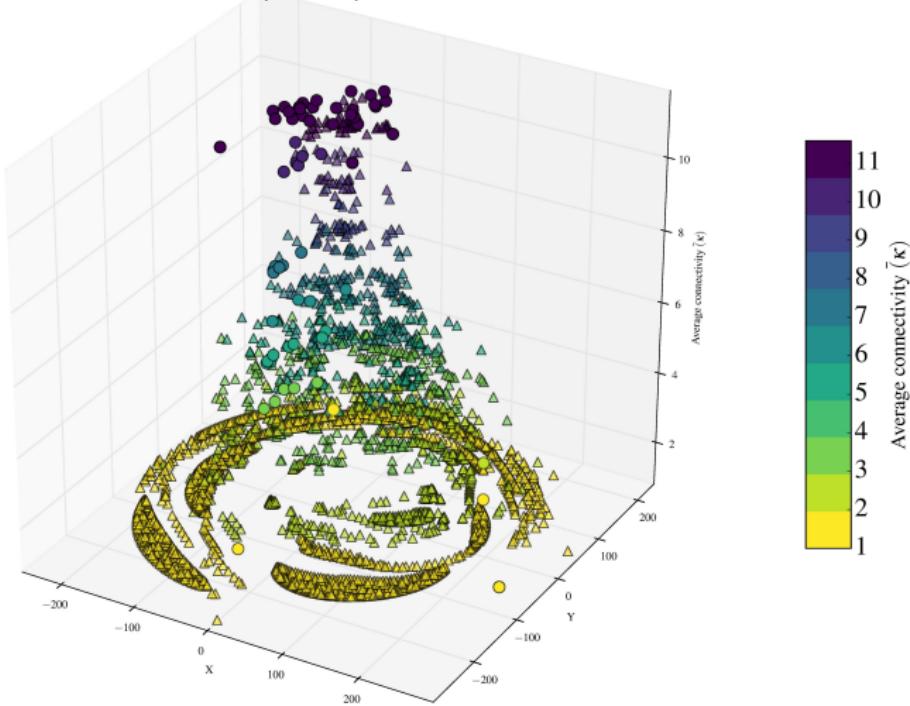
Python 3d scatter plot 2009



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Python Cooperation Network 2010 (63 developers)

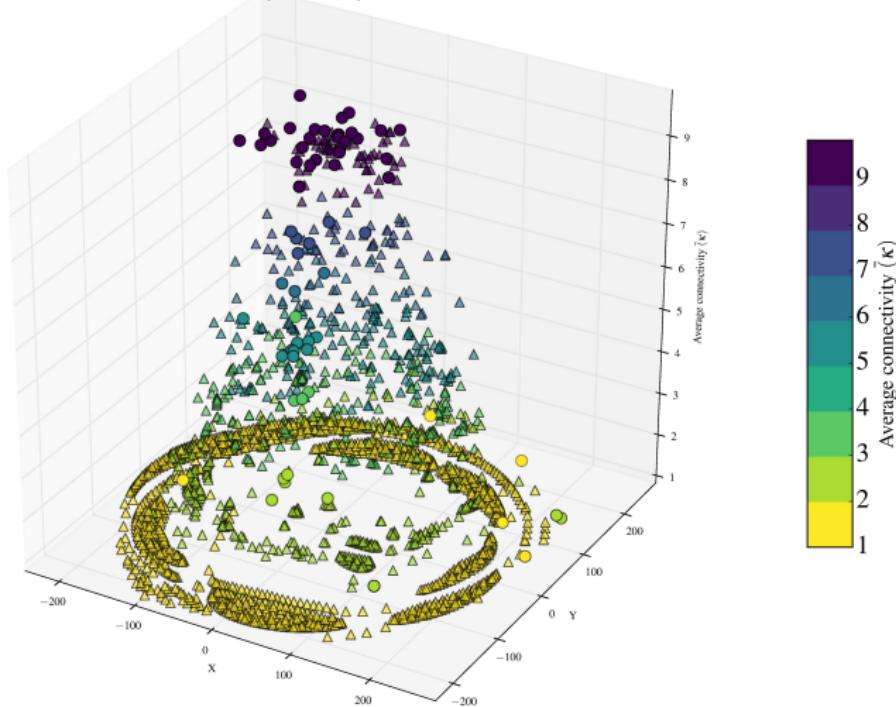
Python 3d scatter plot 2010



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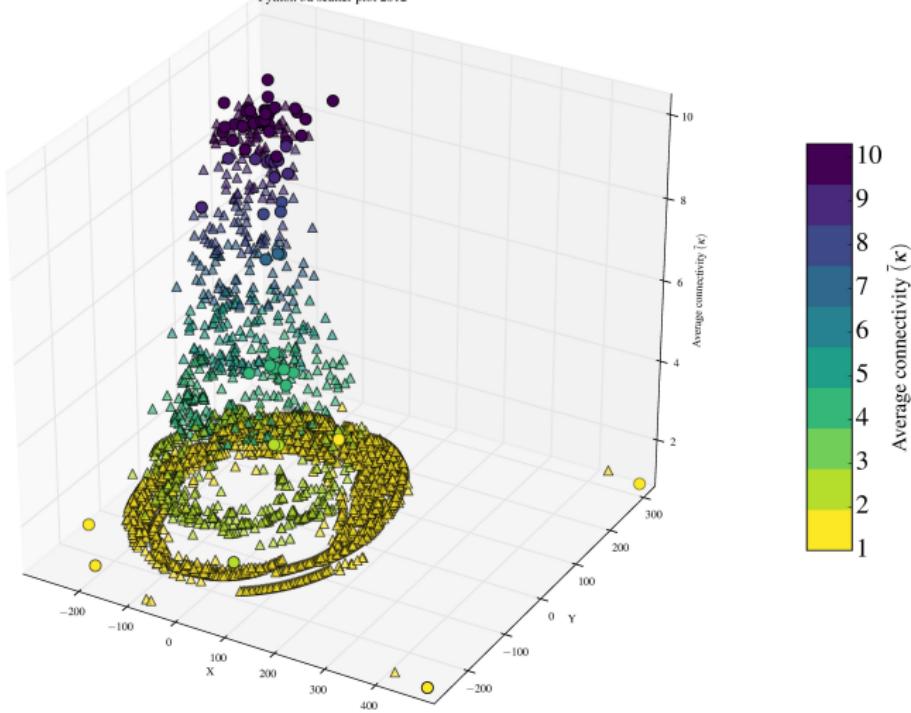
Python 3d scatter plot 2011



Graphical Representation of the Structural Cohesion Analysis

Python Cooperation Network 2012 (65 developers)

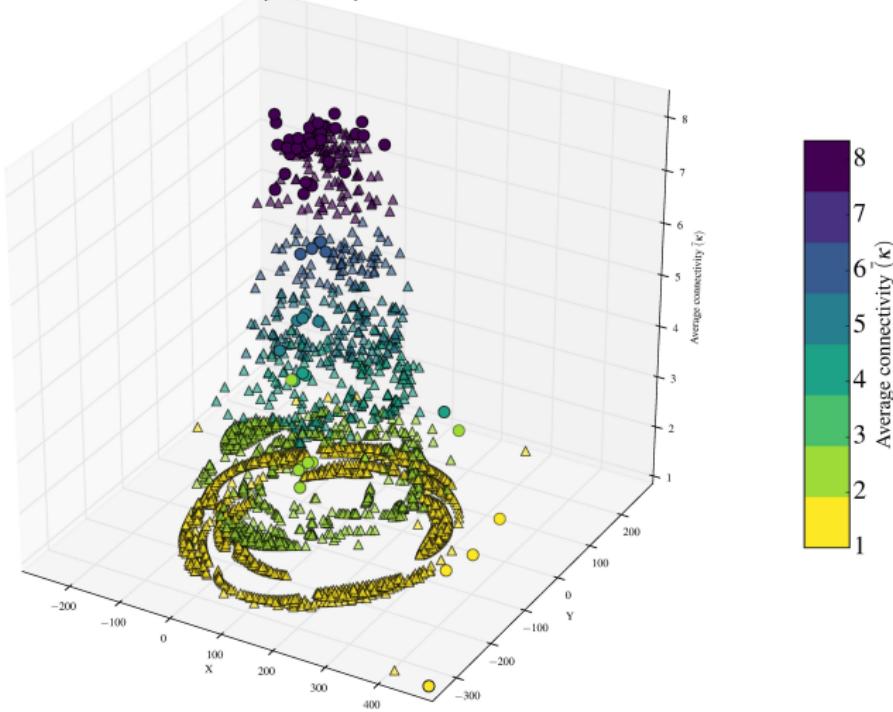
Python 3d scatter plot 2012



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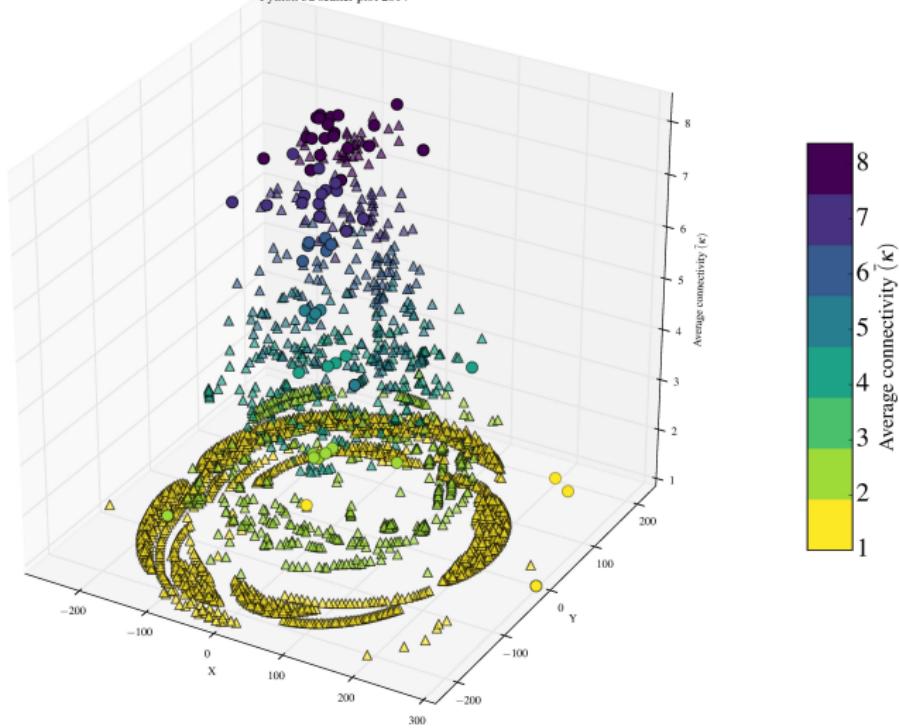
Python 3d scatter plot 2013



Graphical Representation of the Structural Cohesion Analysis

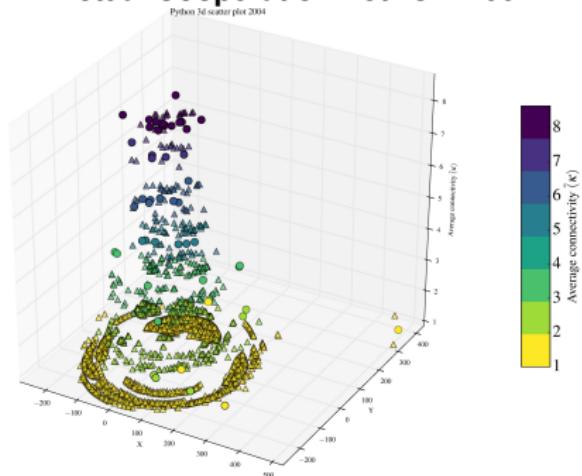
Python Cooperation Network 2014 (62 developers)

Python 3d scatter plot 2014

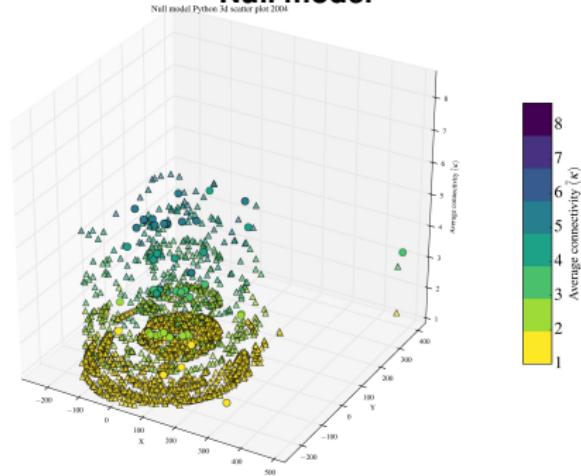


Comparison with null models

Actual Cooperation Network 2004



Null model



The Hierarchical Structure of FOSS projects

Free and Open Source Software (FOSS) communities have attracted a lot of attention from researchers. Academic efforts took mainly two directions:

Reconcile with neoclassical economy

- Mainly focused on the individual motivations of the participants. What is usually referred as “microfundaments”.
- Trying to explain motivations in terms of rational self-interested individuals to match the dominant economic accounts.
- Proposed that individuals

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Uncritically celebratory and a bit naive

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- Supported the ethical stand that valued more cooperation and reciprocity than competition and self-interest.
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Well established empirical fact about FOSS projects

- Only few of the participants account for the lion's share of the work done.
- The deep contribution inequalities may mean that these projects follow the “iron law of the oligarchy” (Shaw and Hill, 2014).
- I propose that one of the central characteristics of FOSS projects is their high ratio of turnover in key hierarchical positions.

Empirical Analysis of Individual Contributions

Longitudinal Analysis of the Social Structure of FOSS projects

The social structure of a community are the patterns of relations established among individual participants in the production process. But I do not limit the analysis to one point in time; I analyze its evolution.

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Puzzle: FOSS projects as Oligarchies?

Michels (1915) “iron law of oligarchy” states that organizations tend towards oligarchy as they grow, even if democracy and participation are part of their core goals.

FOSS projects as Open Elites

The continuous renewal of the people that does most of the work is a key mechanism to explain how FOSS projects can thrive and succeed through time.

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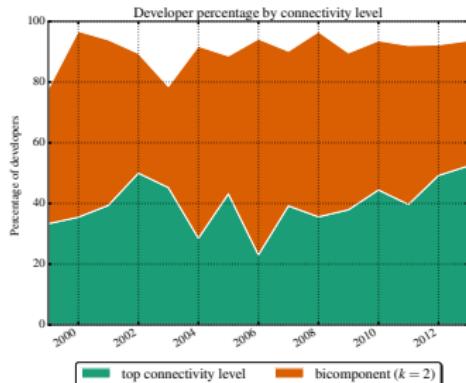
Longitudinal analysis

If we analyze a FOSS project in a concrete point of time, only a very small fraction of the participants are the ones that actually do the lion's share of contributions, as previous empirical research has shown.

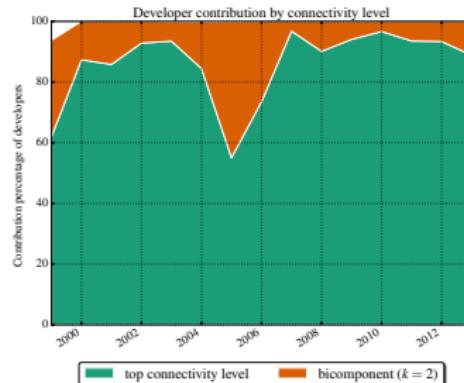
However if we analyze the evolution of contributions longitudinally, we find that the persons that contribute the most change through time.

Individual contributions by connectivity level

- The developers that contribute the most are in the higher levels of the connectivity structure of the project's cooperation networks.
- The hierarchical connectivity structure shapes the volume of contribution of individual developers.



(a) Python: developer % by connectivity level



(b) Python: contributions by connectivity level

Figure: Evolution of the percentage of developers by connectivity level (left) and evolution of the percentage of contributions by developers by connectivity levels (right) in the Python project. The green surface represents the developers in the top connectivity level, that is developers that are part of a k -component with maximum k . The orange surface represents developers in bicomponents, that is k -components with $k = 2$.

Analyzing Source Code Contributions and beyond

To further the analysis I used more sophisticated statistical modeling strategies to assess the impact of the connectivity structure in the individual contributions to the project.

- **Added source code lines to Python:** Modeled with a panel regression with individual and year fixed effect. The position of the individual developer in the connectivity hierarchy is the second most important independent variable only after Degree Centrality.

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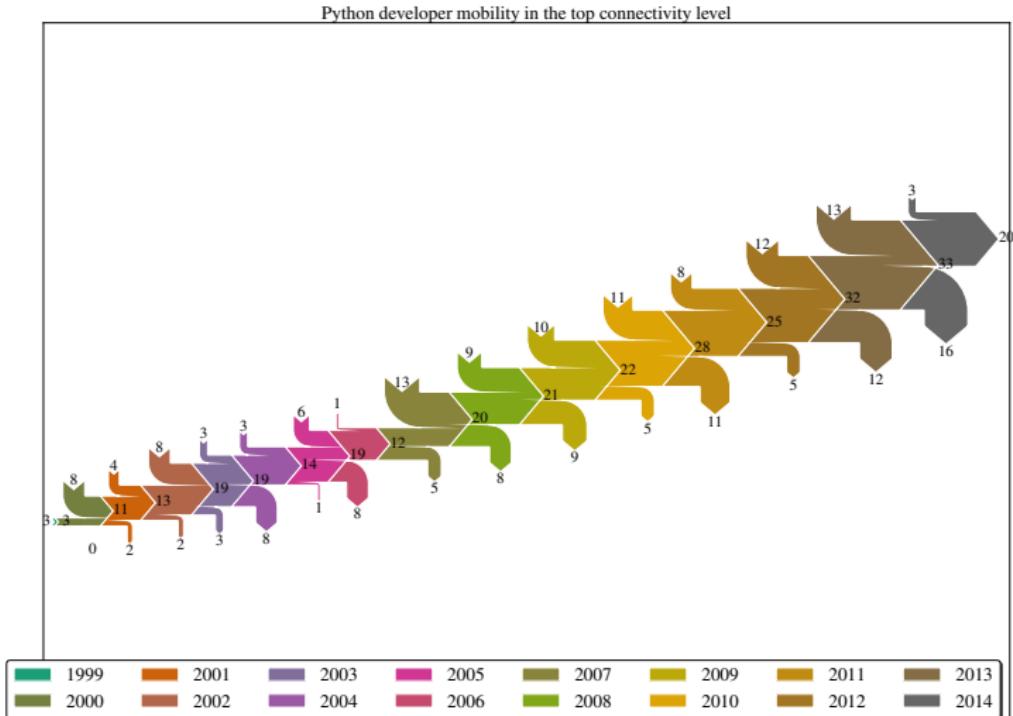
Potential endogeneity problems of the previous model

There is a relation between the dependent variable and the network metrics (independent variables) because the cooperation networks are build precisely based on contributions to the project.

- **Number of accepted Python Enhancement Proposals (PEP):** Modeled with a zero inflated negative binomial. PEPs are design documents that define the language; are thus contributions not directly related to the cooperation networks. Being part of the top connectivity level is also the second most important independent variable, this time only after developer's tenure (in years).

Cooperation Networks' Connectivity Hierarchies as Open Elites

The ratio of renewal of individuals at the top of the connectivity hierarchy is quite fast, which characterizes the CPython project as an open elite.



Usual measures of robustness

- Failures: remove nodes at random and see how this affects the size of the giant component.
- Attacks: remove nodes incrementally starting for the ones with higher degree.

Modeling robustness of Cooperation Networks

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My approach: Survival analysis

- I model active life of a developer as the period that this developer is contributing to the project.
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Cox proportional hazards model

The position of an individual in the connectivity hierarchy impacts significantly their median active life in the project.

- Being part of the top connectivity level decreases the yearly hazard of leaving the project by 77%.
- Also an increment of one connectivity level decreases the yearly hazard of leaving the project by 26%.

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Estimating the survival function with the Kaplan-Meier estimator

$$\hat{S}(t) = \prod_{t_i < t} \frac{n_i - d_i}{n_i}$$

where d_i are the number of “death events” at time t and n_i is the number of subjects at risk of death at time t .

Modeling robustness as median active live of individuals in the project

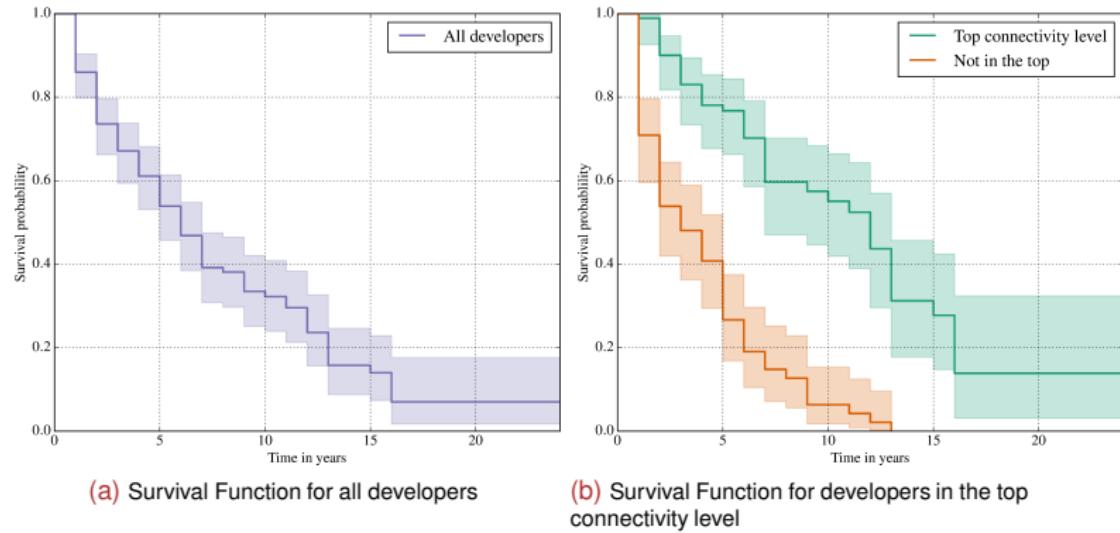


Figure: Estimation of the survival function using the Kaplan-Meier estimate. The median survival time of a developer in the community, defined as the point in time where on average half of the population has abandoned the community, is 6 years if I consider all developers (left). But if I consider separately 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.

Conclusions

- **Cooperation Networks:** A meso level approach to large scale cooperation focused on the patterns of relations that direct producers establish between them in knowledge intensive production processes.
- The nested structure of k -components nicely captures the **hierarchy in the patterns of relations** that individual contributors establish when working together.
 - reflects the empirically well established fact that in FOSS projects only a small fraction of the developers account for most of the contributions.
 - refutes the naive views of early academic accounts that characterized FOSS projects as a flat hierarchy of peers in which every individual does more or less the same.
- **Cooperation has a structural dimension** because membership in cohesive groups has an important and statistically significative impact on both the volume of individual contributions, and on the median active life of developers.
- The connectivity structure of these collaborative communities' cooperation networks can be characterized as an **open elite**, where the top levels of this hierarchy are filled with new individuals at a high pace.
- This feature is **key for understanding the mechanisms and dynamics** that make FOSS communities able to develop long term projects, with high individual turnover, and yet achieve high impact and coherent results as a result of large scale cooperation.

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