

# Online Communities: Visualization and Formalization

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**Abstract.** Online communities have increased in size and importance dramatically over the last decade. The fact that many communities are online means that it is possible to extract information about these communities and the connections between their members much more easily using software tools, despite their potentially very large size. The links between members of the community can be presented visually and often this can make patterns in the structure of sub-communities immediately obvious. The links and structures of layered communities can also be formalized to gain a better understanding of their modelling. This paper explores these links with some specific examples, including visualization of these relationships and a formalized model of communities using the Z notation. It also considers the development of such communities within the *Community of Practice* social science framework. Such approaches may be applicable for communities associated with cybersecurity and could be combined for a better understanding of their development.

## 1 Introduction

The development of collective human knowledge has always depended on communities. As communities have become more computer-based, it has become easier to monitor the activity of such interactions [7]. Recently the increasing use of online communities by the wider population (e.g., for social networking) has augmented the ways that communities can form and interact since geographical co-location is now much less critical than before the development of the Internet and the web [1,2].

Here, we consider the visualization of online communities, their development in a *Community of Practice* (CoP) context [5,17], their formalization using the Z notation [14], and possible applications to cybersecurity.

## 2 Visualization

A community of people can be modelled naturally as a mathematical graph with vertices representing people and edges representing connections between those people. This is not dissimilar to the web with its pages and hyperlinks [13]. The edges in the graph may be undirected (e.g., for friendship between two people where both like each other, or as collaborators in some joint activity such as co-authorship of joint publications [4,6]) or directed (e.g., for a citation of one author to another author's work). Such a graph is a

natural way to visualize relationships between people. When observed visually, patterns in the graph can be quickly assimilated and analyzed by the viewer.

With the increase in social and professional networking online, the visualization of online communities in an automated way as graphs is now relatively easy. For example, Figure 1 shows connections between one of the authors and “friends” on Facebook, using visualization software provided by TouchGraph (<http://www.touchgraph.com>). The TouchGraph Facebook app tool also takes account of links between all the people included in the graph (<https://apps.facebook.com/touchgraph/>). Thus it is possible to note groups within the network visually. Greatly interconnected groups of people are clustered together on the displayed graph and are highlighted using colours. For example, in the case of Figure 1, those towards the right of the diagram are mainly people interested in computer science and those towards the left are mainly interested in museums and the arts, two major but largely non-overlapping areas of interest to the author (in the centre of this diagram). Within the computer science community, several sub-communities are indicated by different colours.

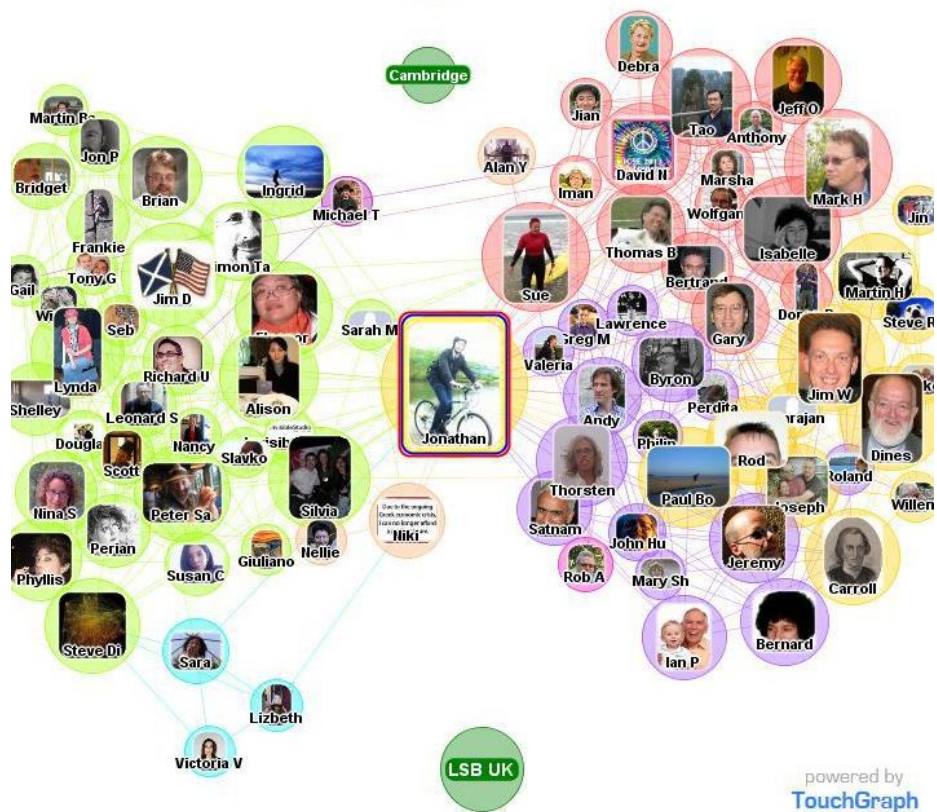
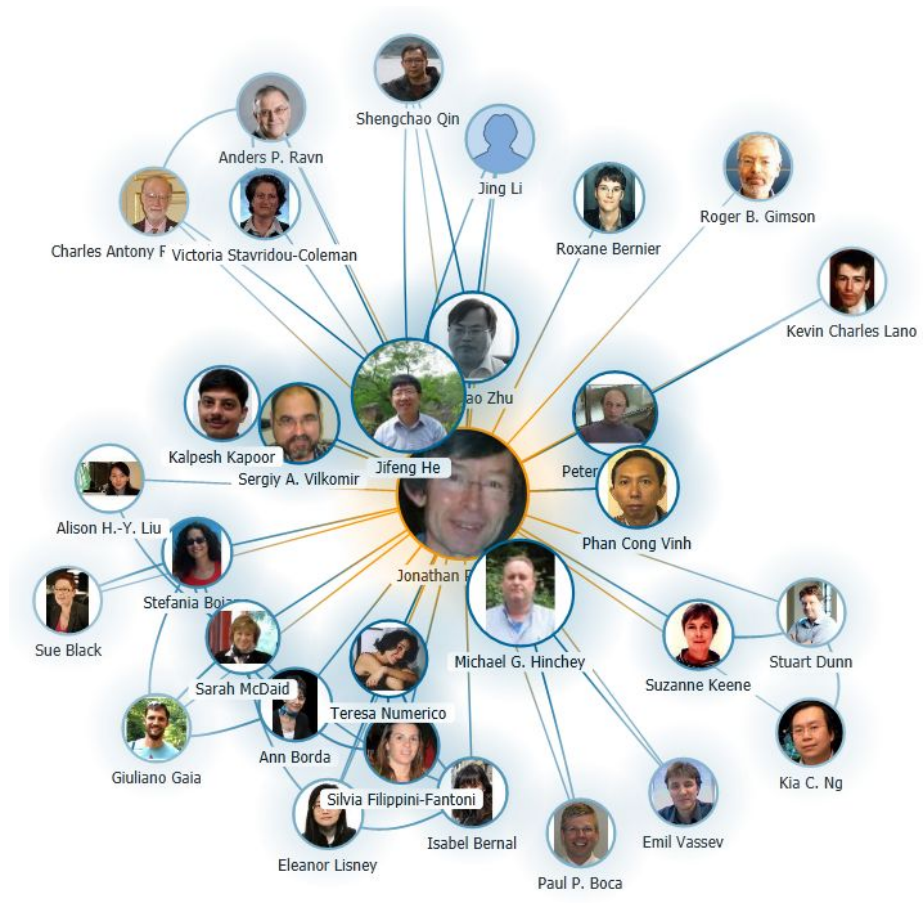


Fig. 1. Facebook TouchGraph connections.

Figure 2 shows a similar set of links for co-authors, provided by Microsoft Academic Search (<http://academic.research.microsoft.com>) as part of its visualization toolset. Here the linking of co-authors in the fields of formal methods and museum informatics can also be observed as linked clusters mainly to the top and bottom of the displayed graph respectively.



**Fig. 2.** Academic Search co-authorship connections.

Similar visualization tools could be applied to a wide variety of communities, especially if the activities of an individual are under investigation (e.g., for cybersecurity reasons). For example, patterns of email connectivity could be displayed in a similar manner.

### 3 Communities of Practice

Increasingly it has been realised that the development of communal knowledge is largely social in character, although it often takes place in a variety of situations, whether in the workplace or some other organization. Such social considerations have also led to the theoretical framework of a *Community of Practice* (CoP) in the social sciences field, with a number of elements, principles, and developmental stages [10,16,17]. A CoP is a group of people with a shared interest or profession, engaged in the developing communal knowledge. It involves situated learning, in which the people that are learning also apply this knowledge in the same context (e.g., during practical experience).

The following three fundamental elements form the structural model of a community of practice [17, chapter 2]:

1. *Domain*: A CoP must have a common interest to be effective. All the participants in the group must be able to contribute in some way within this domain. Otherwise it is just a collection of people with no particular purpose. For example, cybersecurity is such a domain. Formal methods and visualization techniques are other examples.
2. *Community*: A CoP also needs a group of people who are willing to engage with at least some others in the group, so ultimately the entire group is transitively connected as a single entity, from a global viewpoint. This aspect is critical to the effective development of knowledge. The group of people interested in cybersecurity includes both those attempting to protect and break into systems, with some people crossing the the boundary between these two aspects (often as “poachers turned gamekeepers”). This community has expanded rapidly with the rise of the Internet and the web.
3. *Practice*: The CoP must explore both existing knowledge and develop new knowledge, based on existing concepts, but expanded through actual application in a practical sense. This leads to a set of common approaches and shared standards in applying them. In the case of cybersecurity, this includes two specific sub-communities, those wishing to increase the effectiveness of cybersecurity and those attempting to break it.

Developing a successful CoP requires the interplay of these three elements within a community in a balanced manner, because they are all dynamically changing over time, rather than being unalterable. Whilst it is important to have the three elements controlled to a degree in a CoP, perseverance in one element will help ease the potential problems in another. As Wenger et al. have asserted, “*The art of community development is to use the synergy between domain, community, and practice to help a community evolve and fulfil its potential.*” [17, page 47] Without the three elements above, a true CoP cannot evolve. With them, the community can develop a *Body of Knowledge* (BoK) that can be used by practitioners within a particular area of expertise [5].

A critical part of knowledge development is learning. Increasingly it has been realised that this is largely social in character, although it often takes place in the workplace [8]. In this framework, the concept of legitimate peripheral participation (LPP) has been developed [11]. This approach considers how individuals move from being newcomers in a community, eventually becoming experienced in some collaborative

project or endeavour. Often the initial tasks undertaken by participants are small-scale and low-risk. Nevertheless, the act of empowering these peripheral members to participate in a large-scale collaborative project promotes interaction between novices and experts. It has the potential to generate productive knowledge development within the community involved in the overall effort. In the context of cybersecurity, some people may have an initial interest because it has an impact on their work. A proportion of these will go on to become experts in the field, playing a leading role in the defence of an organization that is critically dependent on networked IT for example.

#### 4 Formalization in Z

Communities have been studied in a variety of informal frameworks, such as a Community of Practice as presented in the previous section. Typically there is some form of layered structure to communities with sub-communities combining to form larger communities. Here we suggest an abstract framework that could be used to formulate the structure of communities of people and associated sub-communities. A number of desirable properties can be modelled. The framework is specified using the Z notation [3,14], based on predicate logic and set theory [9], together with schema boxes for structuring the mathematics forming the specification. The choice of Z here simply reflects the experience and background of the author, although Z is particularly good at modelling relations, which are helpful in this context for representing connections between people and their associated communities.

In modelling communities, we initially define a given set, *NAMES* of entities, whether they are people or communities of people.

$$[NAMES]$$

The name space is split disjointly between people and communities that provide structure for related people.

$  \begin{array}{l}  PEOPLE, \\  COMMUNITIES : \mathbb{P} NAMES  \end{array}  $
$PEOPLE \cap COMMUNITIES = \emptyset$

A basic community framework may be formulated as finite sets of people and communities.

$  \begin{array}{l}  Community_0 \\  \hline  people : \mathbb{F} PEOPLE \\  communities : \mathbb{F} COMMUNITIES  \end{array}  $
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Communities contain links between people. The exact nature of the links can be left open at this stage and can be fixed for different situations. In the two examples presented in Section 2, the links presented Facebook “friendship” and academic co-authorship respectively. They could equally well represent email contacts or other forms

of communication, for example. Both people and communities may be members or a part of other communities. Links between people and community membership should be valid. That is, links should relate actual people in the community framework and all communities should exist in the framework.

$Community_1$
$Community_0$ $links : PEOPLE \leftrightarrow PEOPLE$ $memberships : NAMES \leftrightarrow COMMUNITIES$
$dom\ links \subseteq people$ $dom\ memberships \subseteq people \cup communities$ $ran\ links \subseteq people$ $ran\ memberships \subseteq communities$

It is possible to specify people that have no links and entities (people or communities) that are not within any community. People may be “orphans” (i.e., have no links to them):

$Community_2$
$Community_1$ $nolinks : \mathbb{F}\ PEOPLE$ $nomemberships : \mathbb{F}\ NAMES$ $orphans : \mathbb{F}\ PEOPLE$
$nolinks = people \setminus dom\ links$ $nomemberships = people \cup communities \setminus dom\ memberships$ $orphans = people \setminus ran\ links$

It may be desirable for all people to have links and be part of (at least one) community and for all communities to have people and/or sub-communities in them (i.e., for  $nolinks$  and  $nomemberships$  to be empty). It may also be a desirable property for there to be no orphans (i.e., for  $orphans$  to be empty).

We could strengthen earlier constraints. For example, we could specify that all people have links with some other people and are a member of some community. Also, all people are linked from other people in some way and all communities are populated (with memberships of people or sub-communities).

$Community_3$
$Community_2$ $people = dom\ links$ $people \subseteq dom\ memberships$ $ran\ links = people$ $ran\ memberships = communities$

It is normally sensible to limit the model so that people cannot be related to themselves and communities cannot be members of themselves since this is not helpful for structuring. Indeed, loops are not desirable in categorising sub-communities, so it is best to avoid transitive membership (indicated below by  $^+$ , irreflexive transitive closure).

$Community_4$ $Community_2$
$id\ PEOPLE \cap links = \emptyset$ $id\ COMMUNITIES \cap memberships^+ = \emptyset$

There are some (one or more) top-level communities that are not sub-communities of any other community. These top-level communities provide one or more high-level starting points for traversing the information about communities.

$Community_5$ $Community_4$ $tolevelcommunities : \mathbb{F}_1\ COMMUNITIES$
$tolevelcommunities = ran\ memberships \setminus dom\ memberships$

If people are not interlinked in any way, it is questionable why they are relevant in the overall community framework.

$Community$ $Community_5$
$dom\ links \cup ran\ links = people$

The set of people associated with a particular person may be of interest. We can define a status operation, where the state of the overall community does not change.

$LinkedPeople$ $\exists\ Community$ $p? : PEOPLE$ $linked! : \mathbb{F}\ PEOPLE$
$linked! = links(\{p?\})$

(Note that the  $(\{ \dots \})$  notation indicates the relational image of a set.)

The set of common people associated with two specific people may also be of interest:

$CommonPeople$ $\exists\ Community$ $p1?, p2? : PEOPLE$ $common! : \mathbb{F}\ PEOPLE$
$common! = links(\{p1?\}) \cap links(\{p2?\})$

Information on the community membership of a person may be wanted:

$\exists$ <i>CommunityMembership</i>
$\exists$ <i>Community</i>
$p? : PEOPLE$
$communities! : \mathbb{F} COMMUNITIES$
$communities! = memberships^+(\{p?\})$

Here all the different layers of community with which an individual person is involved are returned.

The above Z specification has gradually built up a number of desirable properties in a framework that could be used to specify memberships of a layered set of communities together with some example status operations on the overall community. Further properties of communities could be added within this model. It is suggested that an abstract framework such as this could be useful for formulating a conceptual model of communities and used as a starting point for further reasoning about and modelling of communities. This framework could be used as a basis for visualization tools of communities.

## 5 Conclusion

We have briefly considered visualization, development, and formalization of communities of people using existing online software tools, a Community of Practice framework, and the Z notation respectively. Visualising virtual communities has become increasingly easy over the past decade as social and professional networking has developed rapidly. Online software tools are improving in this regard. Communities of practice, as postulated in the social science field, could be studied further for a variety of communities [5,12]. In particular, visualization of these communities dynamically over time could help in understanding their nature as they grow and contract. Z has proved to be an elegant formalism for capturing precise descriptions of various aspects of connections between people and associated entities due to its ability to model relations in a natural way [4,5].

In summary, combining ideas from visualization and the Community of Practice framework, underpinned by formalization in a notation such as Z, could be any interesting area for further exploration. It can be expected that visualization of online communities will improve significantly over the next decade just as the communities themselves have developed and expanded rapidly over the past decade. Further formalization could help with understanding the nature of communities and the relationships of people within them. Such studies could be helpful in cybersecurity, with respect to online communities associated with breaking security for example.

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