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Abstract

Funded by nonprofit organization Wikimedia, Wikipedia is a free, openly-accessed and collaboratively-edited encyclopedia available online. What makes Wikipedia such a remarkable human feat is that not only has it become the largest general reference network on the net,[1] but it has accomplished this through bottom-up, volunteer-initiated, user-generated content. Wikipedia's self-organizing mechanism mediates indirect interaction between collaborators. When communication is channeled in the environment triggering agents to take action, this is called stigmergy. Stigmergy was first defined in 1959 by zoologist Pierre-Paul Grassé[2], whose research focused on collective behavior of social insects. From 1990 onward, stigmergy as a process occurring in human self-organization has also been explored,[3] yet little is known about how human stigmergy manifests and how systems can be designed in order to promote stigmergic outcomes. This paper will first define relevant terminology in the field of stigmergy, including self-organization, complexity and emergence. Control hierarchies will be introduced in the context of their failure to cope with growing complexity, and a need for exploring alternative organization methods will be raised. Wikipedia, a stigmergy-driven platform, will be used as a valid and useful environment for researching human stigmergy. The vast data-mining opportunities afforded by Wikipedia's revision database will be discussed, as well as the practical limitations in interfacing with such big data. A case will be made for using visualization as a means for aggregating and analyzing Wikipedia data and a new mapping tool, *Trace*, will be presented. Through extracting design patterns from Trace maps, a new avenue for human stigmergy research can be realized. Finally, Trace will also be proposed as a useful tool for exploring other related topics including epistemology, conflict resolution and global brain research.

[1] "Wikipedia," Wikipedia, accessed August 3, 2013, http://en.wikipedia.org/wiki/Wikipedia.
[2] Leslie Marsh and Christian Onof, "Stigmergic Epistemology, Stigmergic Cognition," *Cognitive Systems Research* 9, Issues 1-2, March 2008, 2.
[3] Francis Heylighen, "Stigmergy as a Generic Mechanism for Coordination: Definition, Varieties and Aspects," *ECCO, Vrije Universiteit Brussel*, 1.

Self-Organization & Stigmergy

When a flock of birds takes flight and naturally forms a "V" shape in the sky, this happens through a spontaneous, decentralized process where each bird situates itself based on its location in relation to the birds closest to it.[4] There is no "Chief Executive Bird" organizing the flock, assigning locations, directing a path, or supervising the flight. The mechanism that fosters such behavior is called self-organization. Self-organization is when coordination emerges out of local interactions between agents of an initially disordered system[5]. With self-organization, animals share information immediately and respond collectively to increase their chances for survival of the group and the individual; self-organization helps animals accomplish critical, time-sensitive and complex tasks such as escaping predators or hunting prey.

While self-organization focuses on the general process of *organization*, stigmergy is a self-organizing process that includes the element of work and production. If the work of one agent (animal) stimulates the continued work of another, this is called stigmergy.[6] With stigmergy, feedback within the environment acts as a design engine triggering spontaneous initiatives by contributors.[7] This self-organizing process explains how social insects find food across vast areas and build their complex nests.

Three basic components of stigmergy include the *agent*, the *medium* and the *trace*. The agent is defined by an "autonomous, goal-directed system,"[8] such as a bird in a flock, a food-seeking ant or a nest-building termite. With stigmergy, agents either produce or stimulate an action within an environment, or more accurately: within a *medium.*[9] While "environment" may be frequently used to describe this context, medium is a more accurate term because a medium can be perceived and controlled, whereas an environment usually refers to something outside of a system that in many instances cannot be controlled.[10] The last component within a stigmergic system is a *trace*, an

[4] Kevin Kelly and Andreas Lloyd, "Bootstrapping Complexity," (Kevin Kelly, Pacifica, CA, 2011), Kindle edition, Location 301.
[5] Francis Heylighen, "Self-organization in Communicating Groups: the Emergence of Coordination, Shared References and Collective Intelligence," in Language and Complexity. (Barcelona University Press 2011), 3.
[6] Francis Heylighen, "Why is Open Source Development so Successful? Stigmergic Organization and the Economics of Information," in *Open Source*, ed. B. Lutterbeck, M. Baerwolff & R. A. Gehring, (Lehmanns Media, 2007), 7.
[7] Ibid.
[8] Heylighen, *Stigmergy as a Generic Mechanism,* 6.
[9] Ibid.
[10] Ibid.

intentional or unintentional signal placed in the medium stimulating either the same agent or another to take action.[11] Together, the agent, medium and trace make it possible for two types of stigmergy to manifest: *quantitative* or *qualitative*. [12] [13]

Quantitative stigmergy is a quantity-driven ranking system that helps agents decide which option is most favorable out of all available options. For example, when ants successfully find food and bring it back to their nest, they emit a pheromone (trace) into the air (medium). Other ants in pursuit of food will detect and follow the trail of pheromones until the source of food is found. As more ants follow the trail and bring back food to the nest, more pheromones are released into the air. These pheromone trails make it abundantly clear to ants leaving the nest in pursuit of food, which direction is most promising.

While quantitative stigmergy uses the medium as a tool for prioritization and decision-making, direct qualitative stigmergy uses the medium as a platform for change on the medium itself. An example of qualitative stigmergy can be demonstrated in the way ants and termites build their nests:[14] termites drop a bit of mud in a random place; this stimulates other termites to add mud (rather than start a mud-pile of their own); with time, a complex nest is built, providing termites with security, shelter, nurseries, agriculture, ventilation and a thermostat accurate within a two-degree threshold.[15] The termites do not communicate about who is to do what how or when;[16] communication is brokered through the medium itself and evolves as the agents react and modify it.

Emergence & Complexity

Self-organization decentralizes control and ties the behavior of the individual with the structure and functionality of the group.[17] When this happens, there is no hierarchic function in control and new outcomes emerge without a prerequisite foresight or plan. The "what" is generally understood, the "how" is spontaneously improvised. This

[11] Heylighen, *Stigmergy as a Generic Mechanism*, 7.
[12] Heylighen, *Why is Open Source so Successful?* 15.
[13] Terminology also used to define stigmergy includes, indirect and direct (Heylighen); or "Sematectonic" and "Sign-, Cue-, or Marker-based," (Marsh, Onof)
[14] Heylighen, *Why is Open Source so Successful?*, 7.
[15] BBC The Trials of Life: Home Making, "Termites," YouTube video, 8:20, accessed July 4, 2013, http://www.youtube.com/watch?v=ld07xdqnytk.
[16] Heylighen, *Why is Open Source so Successful?*, 7.
[17] Heylighen, *Self-organization*, 3.

spontaneous improvisation leads to *emergence*, when a multitude of simultaneous actions creates a unique and unpredictable outcome rather than a series of singular actions aggregated into one predictable and exponentially amplified outcome.[18] With emergence, "more" isn't just more, it's "different".[19] The benefit of such a scenario is that the individual becomes part of a broader collective, greater than oneself, and can thereby cope with a higher level of complexity. Complex systems have emergent properties that cannot be reduced to smaller or simpler parts. While they are unpredictable and irreversible, they also rely on spontaneous self-organization to adapt and evolve.[20] This is what makes them resilient in the face of dynamic external forces that may pose a risk to their stability and existence. Coping with complexity is critical to survival; organisms unable to cope with the complex demands of their dynamic environment have a lower survival rate, regardless of how well-adapted they are.[21]

In human civilization, complexity, self-organization and emergence occur in "unintended" circumstances. One such example can be demonstrated through Adam Smith's "invisible hand,"[22] a metaphor used to describe the self-regulating behavior of markets. While humans are familiar with complex systems and emergent events in uncontrolled formats, civilization has relied on a simpler and in some ways contradictory mechanism to organize and accomplish tasks: control hierarchies.

Control Hierarchies & Their Limitations in the Face of Rising Complexity

For thousands of years, conventional scientific thought has relied heavily on Newtonian mechanics generically described as the possibility to break down an object into its smaller parts and reconstruct it back into its original form.[23] Such a mechanical system is the direct opposite of a complex system, which cannot be broken down into smaller sub-parts. One of the great benefits of Newtonian mechanics is that it offers straightforward and predictable outcomes. Its weakness lies in its inability to cope with

[18] Kelly, Lloyd, *Bootstrapping*, Location 536.
[19] Ibid.
[20] Heylighen, *Self-organization*, 2.
[21] Yaneer Bar-Yam, "Complexity Rising: from Human Beings to Human Civilization, a Complexity Profile," *New England Complex Systems Institute*, 18.
[22] Francis Heylighen, "The Science of Self-organization and Adaptivity," *ECCO, Vrije Universiteit Brussel*, 4.
23 Francis Heylighen and Clément Vidal, "Getting Things Done: The Science behind Stress-free Productivity," *ECCO, Vrije* Universiteit Brussel, 2.

complex circumstances, a growing requirement as the world and human civilization are becoming more complex. The limitations in control hierarchies can be demonstrated in two conventional scenarios: organization management and individual task management. Humans have organized themselves for thousands of years via top-down control hierarchies.[24] Unlike complex self-organizing systems, hierarchies are linear, top-down systems where control and information are centralized.[25] From kingdoms led by monarchies to organizations led by hierarchies, humans have relied on a top-down linear mechanism for organizing and achieving goals. These achieved goals point to large and impressive accomplishments like the building of the pyramids of Egypt, or sending a man safely to the moon and back. Yet, however great these accomplishments, the hierarchic method of organization is far from able to cope with growing complexity in modern times "directly related to sweeping changes in the structure and dynamic of human civilization – the increasing interdependence of the global economic and social system, and the instabilities of dictatorships, communism and corporate hierarchies."[26] Bottlenecks, rising costs, output lags and delays and corruption can oftentimes be attributed to hierarchy unable to keep up with demands of a complex environment.

To add to this, the evolution of information has greatly added to the level of complexity. Namely, the reduction of barriers for accessing it and the sheer amount of it made publicly available. Access to information has become a direct challenge to control hierarchy management for two main reasons. First, when once information was centralized and used as a powerful tool to lead and manage the mostly ignorant masses, today anyone with a mobile device and an Internet connection can find out almost anything with a tap of a finger. Second, due to the dynamic nature of information, planning too far in advance is a futile effort as information continues to change at a faster and faster pace.

In a situation where new information may arrive by the minute, both the relevant options and the criteria for where new information may arrive by the minute, and

24 Bar-Yam, Complexity, 14.

25 Kelly, Lloyd, *Bootstrapping*, Location 571.

26 Bar-Yam, *Complexity*, 1.

the criteria for deciding between them are constantly changing…Rationality is bounded: we never have the full information needed to make optimal choices.[27]

The overflow of information has undermined control hierarchies. This strain can be demonstrated in the modern, hierarchic business organization where managerial leadership is reserved to those few ranked at the top. With hierarchy in its idealized and theoretical state, collective behavior of an organization is controlled by management responsible for leading, communicating and coordinating all parts of the organization.[28] In its more realistic context, as an organization grows with more people to manage, and as more information and knowledge are required to specialize and produce, so grows complexity and demands on managing it. Rising complexity makes it impossible for an executive manager to communicate and "control" every single person in the organization; there is only so much a person at the top of a control hierarchy can know or understand at any given moment; there is only so much expertise one individual can demonstrate on a particular subject; and there are only so many hours in the day for one manager to address the many needs that can arise.

To cope with growing complexity, those in leadership positions are likely to reference individual task management paradigms. However such attempts are also flawed, ironically for the same reason company task management is: they too are founded on control hierarchy paradigms. In its idealized form, the individual task management paradigm[29] is based on establishing high-level personal objectives, breaking them down into project milestones and tasks for completion, assigning priorities and delegating work. Target deadlines are set based on work estimations and actions are completed in sequence until the final objective is achieved, on time. In reality however, attempting to predict, prioritize and delegate all potential variables and scenarios in advance requires considerable knowledge, time and resources. Ultimately this can result in an unworkable, unachievable plan that is either too ambitious or too rigid.[30] If a manager is unable to

27 Heylighen, Vidal, *Getting Things Done,* 2.

28 Bar-Yam, *Complexity,* 17.

29 Heylighen, Vidal, *Getting Things Done,* 2.

30 Ibid: 16.

"read the map", set priorities and delegate accurately, then any attempts to organize may be just as valid as no attempts at all.

Control hierarchies are based on linear, mechanical structures challenged by an environment growing in complexity. "The complexity of a system's behavior is fundamentally related to the complexity of challenges that it can effectively overcome."[31] This implies that as the world is becoming more complex, new complex mechanisms for collaborating and accomplishing shared goals are required. As complexity grows, human organization must overcome a coordination dilemma of division of labor. Organizations must either find a supervisor that has "extensive knowledge of the necessary tasks and of the individuals' degree of skills, and the intelligence necessary to conceive of all the different possible permutations of agent-task assignments and to select the best one,"[32] or, refer to self-organization and stigmergy where each person has the natural inclination to do what they do best. While the hierarchic structure may have served humanity for thousands of years, it is no longer enough to keep us moving forward. Complexity is a modern circumstance of which few tools are available for coping. The paradigm may have shifted, but the old way of organization is securely in place; while humans are experts in building centralized organizations, designing for stigmergic, self-organizing systems is a new and little-understood field[33] which requires considerable research. Environments where human stigmergy is happening can provide opportunities for such research.

Stigmergy & a Note about Social Insect Semantics

Proposed as an alternative to hierarchic organization, stigmergy offers a new way for humans to organize. It is interesting to note however, that even semantics used in the classification of social insects relies on hierarchy-based paradigms, for example, "queen bee", "soldier ants", etc. While such analogies are meant to describe the activity, they nonetheless also allude to a hierarchic rank of authority. However, it is important to remember that while each insect fulfills a different role within the colony, there is no top-

31 Bar-Yam, *Complexity*, 2.
32 Heylighen, Vidal, *Getting Things Done*, 8.
33 Heylighen, *Self-organization*, 4.

down supervision or management. "No one bee is in charge. The queen doesn't tell [other bees] what to do. There's no central authority."[34] The authority or rank of the queen is no higher than the soldier ants assigned with the task of bringing in food to the nest. Social insect colonies vary in their organization structure. In fact, some ant colonies have multiple queens, while others have no queen at all.[35] The point of this is to demonstrate the power of semantics and how even in the most complex systems where control is decentralized, human-assigned titles based on control-hierarchy paradigms affect how a system and its agents are perceived. This is not to suggest necessarily that the semantics used in entomology should be replaced with less hierarchy-inspired analogies, but rather to draw attention to the fact that thinking in a hierarchy perspective is deeply ingrained in world perceptions and paradigms. Dr. William Morton Wheeler, considered a leading authority on social insects and responsible for the taxonomy of many organisms, was also the first to view the organization and interaction between social insects as a collective by coining the term *superorganism*. "Wheeler replaced the "reduce-it-to-its parts approach with the see-it-as-a-whole approach".[36] In pursuit of complex objectives, it may be worthwhile to shift thought paradigms from top-down hierarchies to bottom-up systems, from hierarchic organization to a collective and complex superorganism.

Human Stigmergy Online & Wikipedia as Case Study

Technology and information have made the world more complex for humans; however both also provide humanity with new tools for overcoming complexity via the World-Wide Web. The web has decentralized information, granting open and easy access to knowledge. With the web, individual intelligence is enhanced by a collective, open source of knowledge and information where every person has equal access and can also actively contribute. Early usage of the Internet was driven by researchers looking to cooperate and share information.[37] As the web has evolved and developed into a thriving

34 "The Bee Queen," University of Minnesota Alumni Association, accessed September 10, 2013, http://www.minnesotaalumni.org/s/1118/content.aspx?sid=1118&gid=1&pgid=1527.
35 Christian Peeters and Bert Hölldobler, "Reproductive Cooperation between Queens and their Mated Workers: The Complex Live History of an Ant with a Valuable Nest," Proc. Natl. Acad. Sci. USA 92, 1.
36 Kelly, Lloyd, *Bootstrapping*, Location 317.
37 Heylighen, *Why is Open Source so Successful?*, 2.

center for commerce, today many websites and web-based communities still maintain the pioneering web's open and collaborative spirit. Environments such as open-source platforms and websites built by user-generated content give people the ability to actively and independently contribute to a pool of growing knowledge. People are organizing themselves and creating common value together. Websites promoting the collaborative development and sharing of knowledge are oftentimes driven by self-organizing stigmergy.[38] One platform showcasing the power of successful human stigmergy is Wikipedia. Because it meets the requirements for stigmergy and makes available a rich archive of date, Wikipedia is excellent environment for researching stigmergy.

Founded in January 2001, Wikipedia invites anyone with a computer and Internet connection to add from their personal insight and expertise to a pool of global knowledge. Though limitations, restrictions or in extreme cases, sanctions can be imposed on writers with a history of vandalism or disruptive behavior, the editing process is public and any person with the sincere desire to create or make changes to an existing article can do so. As Wikipedia has grown, its open and collaborative environment has supported the creation of 30 million articles in 287 languages written by volunteers.[39]

While it isn't driven by a hierarchic structure, Wikipedia does rely on some form of hierarchic organization to work. Ranks within Wikipedia are assigned based on how active and reputable a person is within the platform, in effect determining a person's ability to make changes to Wikipedia content. That said, Wikipedia still offers one of the most open platforms for human collaboration and sets the right conditions balancing top-down management with bottom-up human stigmergy. Therefore the process of studying stigmergy within Wikipedia also involves understanding how the existing hierarchy plays a role in the collaborative process, and how much it inhibits or enables stigmergy to occur alongside it.

Comparable to traditional encyclopedias such as Encyclopedia Britannica, Wikipedia has been recognized as a legitimate and accurate reference, particularly over a wide range of technical topics.[40] Such an astounding accomplishment could not have

[38] Francis Heylighen, "Accelerating Socio-Technological Evolution: from Ephemeralization and Stigmergy to the Global Brain," in *Globalization as an Evolutionary Process: Modeling Global Change*, ed. George Modelski, Tessaleno Devezas, and William Thompson (London: Routledge, 2007) , 13.
[39] "Wikipedia."
[40] Simon DeDeo, "Evidence for Non-Finite-State Computation in a Human Social System," *Santa Fe Institute*, 3.

been reached by a privately or publicly-funded initiative, nor could it have been achieved by a control hierarchy, managed by an editor-in-chief, supervising and approving all content before publicly publishing. Wikipedia works because of its stigmergic properties where: the Wikipedia article acts as the medium; people contributing their work are agents; and the traces prompting people to take action are the submitted texts, deletions and even vandalism. Three motivators driving Wikipedia's stigmergy structure include:

1. Added Value: different agents have different forms of expertise and therefore can do more together than individually.[41]

2. Incentive: the benefits of getting access to all other people's contributions are a significant payback for one individual's contribution. One gets exponentially more than one gives.[42]

3. Efficacy: distributing tasks or problems across a large population results in a faster, cheaper, more effective way to tackle complex challenges like creating the world's largest source of human knowledge.[43]

Emergence from Turbulence & Friction

The Wikipedia editing process supports behavior that is considered non-finite-state,[44] meaning that the content of each Wikipedia article has an infinite amount of potential versions. This confirms the spontaneous stigmergic mechanism that leads to the emergence of an article. The power of such a complex system is that it manages to remain in a constant state of organized chaos, or "almost-fell."[45] Such a characteristic is unique to dynamic "living" systems also referred to as *Vivisystems*[46] which are decentralized, autonomous, highly connective and offer indirect interactivity between peers.

[41] Heylighen, *Self-organization,* 11.
[42] Heylighen, *Why is Open Source so Successful?,* 5.
[43] Heylighen, *Stigmergy as a Generic Mechanism,* 13.
[44] DeDeo, *Evidence,* 9.
[45] Kelly, Lloyd, *Bootstrapping,* Location: 1751.
[46] Kelly, Lloyd, *Bootstrapping,* Location: 571.

> Life is a networked thing – a distributed being. It is one organism extended in space and time. There is no individual life. Nowhere do we find a solo organism living. Life is always plural…Life entails interconnections, links, and shared multiples.[47]

Examples of vivisystems include: the economy, a natural ecosystem, an immune system or an evolutionary system.[48] Based on such criteria, Wikipedia too can be considered a vivisystem. The stigmergic foundation of Wikipedia makes it so that changes made to Wikipedia, whether synergetic or controversial, help the article and Wikipedia as a system evolve. "The central property of life is not reproductive invariance, but reproductive instability."[49] This also holds true with Wikipedia, where a dynamic environment pushes the site to continually develop and grow every hour, minute, second and millisecond.

Wikipedia Critical Success Factors

A distinct differentiation between Wikipedia and traditional encyclopedias is that Wikipedia is looking to engage not only expert and professional writers, but also "ordinary" people who may not have much experience writing formal references, yet have specific expertise on particular subjects. To encourage people to contribute freely, the system must be open to all and simple to use; too many requirements may act as barriers preventing useful contributions. Wikipedia exists on the basis of two conditions: the ability of the system to attract and allow any person, from amateur writer to professional expert, to contribute; and the ability to defend the integrity of the system as a credible resource of information. These conditions are simultaneously met with Wikipedia's stigmergic structure,[50] enabled by Wikipedia's "View History" function.

Wikipedia View History

[47] Kelly, Lloyd, *Bootstrapping*, Location: 2256.
[48] Kelly, Lloyd, *Bootstrapping*, Location: 1751.
[49] David Layzer, "Cosmogenesis," in Kelly, Lloyd, *Bootstrapping Complexity*, Kindle Edition, Location: 1751.
[50] Heylighen, *Why is Open Source so Successful?*, 9.

Located at the top right corner of every Wikipedia page is the “View History” tab allowing anyone to view and compare every single change ever made to an article. The View History tab is a sophisticated tool at the backbone of the Wikipedia platform because it serves two purposes: it enables an open and public editing environment and it successfully safeguards the integrity of the platform. By saving every version of an article, Wikipedia not only creates a forgiving work environment for non-professional editors otherwise apprehensive about submitting texts to an online website, it also fosters a resilience in the system by giving it the ability to “bounce back” and revert unfavorable changes made unintentionally or otherwise.

As with any open and interactive environment, Wikipedia is also fertile ground for disagreements, disputes, and in more extreme cases edit wars and vandalism. Adding subjective opinions, writing irrelevant texts or deleting entire articles altogether can be considered vandalism and are easily achieved within Wikipedia’s open editing environment. However Wikipedia’s history mechanism makes it possible for “non-vandals” to manually revert back and restore previous, credible article versions. This “revert” mechanism which replaces the current vandalized version with a previous, non-vandalized version, acts as a sort of “undo” button. Yet what makes the revert action even more powerful than “undo”, is that each revision is stored in the article’s history; instead of erasing, revert is a process of saving and restoring. This is especially useful in researching the collaborative process as it unfolds over time.

Rich Database

An indirect output of Wikipedia’s historical function is a rich, detailed and chronological archive of information documenting each change made, version saved and vandalism ever performed on a page from creation date to present day. This automatically generates a rich database of information that can be mined for the purposes of researching how human stigmergy in Wikipedia works. The data is available for the taking, yet the challenge lies in translating such a big resource of data into meaningful information. Data files are large, offering details about each revision ever recorded. Some articles have as many as 30,000 revisions; an exorbitant amount of data to navigate through and make

sense of. Data is meaningless until it is organized.[51] Once organized, the opportunity to form an impression and extract insight is presented. One solution for coping with big data documenting a complex network is visualization; through design data can be transformed into meaningful information. "At the heart of diagrammatic models are visual relations as ways of thinking. The linguistic elements specify referents. The pictoral/graphic elements specify relations."[52]

From Tree to Rhizome: A Brief Background on Visualization

Indicators of stigmergy at play in social insects can be seen with the naked eye via trails of ants or structures of complex nests. These physical and visual markers invite a deeper investigation into how such formations or structures come about. Eventually upon further research, the stigmergic engines such as pheromones or indirect traces in the medium can be discovered. Seeing stigmergy at work is a useful tool for "knowing where to look" for behaviors and structures that point the way to meaning, insight and understanding. This poses the question, how can stigmergy in the Wikipedia medium be visualized in a way that leaves room for exploration and discovery? While each revision is available for review and comparison in the View History section, the collaborative editing process itself cannot be seen. This is analogous to seeing one ant nibbling on a crumb, instead of a trail of ants from crumb to nest. Additionally, exporting the detailed data into tables or grids does not create an environment conducive to exploration and discovery where patterns and indicators can be perceived by the naked eye. If an attempt to visualize stigmergy in Wikipedia is to be made, the first step is to understand which tools are optimal for this pursuit.

The rise in numerical statistical thinking was accompanied by the rise of visual thinking in the 18th and 19th centuries. [53] It was at this time when statistical graphics were recognized as useful tools for exploration, discovery and identifying patterns and trends.[54] As methods and techniques were developed over the next centuries, the design

[51] Elzbieta T. Kazmierczak, "Design as Meaning Making: From Making Things to the Design of Thinking," Design Issues 19 (2003), 46.
[52] Kazmierczak, *Design as Meaning*, 53.
[53] Michael Friendly, "Milestones in the History of Thematic Cartography, Statistical Graphics, and Data Visualization," Web document, http://www.math.yorku.ca/SCS/Gallery/milestone/milestone.pdf, 1.
[54] Ibid.

of bar and pie charts, histograms, line graphs and time-series plots emerged with the clear objective: to "speak to the eyes."[55]

Until the mid-twentieth century and particularly in the case of networks, the tree metaphor has been used to classify, rationalize and illustrate data.[56] The tree schema can be characterized by hierarchic distribution of relationships, linear connections and centralized control.[57] While the tree structure is successful at organizing simple, one- or two-dimensional information, it becomes severely flawed as more dimensions are added; or in other words, as complexity rises. Standard data visualization in the form of grids, lists and spreadsheets are unproductive in visualizing complex data because relationships, processes and changes over long stretches of time cannot be successfully conveyed.

In the mid- to late 1970's, the French philosopher Gilles Deleuze with psychotherapist and philosopher Félix Guattari proposed an alternative to the tree layout. They proposed a rhizome, a nonhierarchical, decentralized model where connections between points have multiple entryways and exits.[58] The benefits of such a layout are that more information, including relationships, connectedness, processes and interdependencies can be illustrated. Just a few years prior, architect Christopher Alexander published a paper, "A City is Not a Tree", exploring the complexity in urban planning and making the argument that a city should not be designed based on a tree structure, but rather a semi-lattice.[59] As Alexander explains, both structures represent sets, defined as a collection of elements with a shared relationship. However one clear distinction between a tree and a semi-lattice is that semi-lattices can visually convey complex structures while trees cannot.[60]

In the mid-1960s, the advancement in technology in the form of computer science research, data analysis and display and input technology (including the invention of the computer mouse) enhanced the field of data graphics, spawning the growth of new visualization methods and techniques.[61] This enhancement corresponded well with the

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[55] Friendly, *Milestones*, 10.
[56] Manuel Lima, *Visual Complexity Mapping Patterns of Information*, (New York: Princeton Architectural Press, 2011), 21.
[57] Ibid, 17.
[58] Gilles Deleuze and Félix Guattari, "Capitalism and Schizophrenia," in Manuel Lima *Visual Complexity*, 44.
[59] Christopher Alexander, "A City is Not a Tree," Reprinted in *Design Magazine* in 1966, Originally published in: *Architectural Forum*, 122 (1), (April 1965): 58-62 (Part I), 122 (No 2), (May 1965): 58-62 (Part II), 3.
[60] Ibid, 5.
[61] Friendly, *Milestones*, 3

growing need to handle substantially larger and highly complex networks which otherwise could not be encapsulated by a clear mathematical formula. While new shapes and structures have made it possible to illustrate complex relationships, [62] new modern technologies have made it possible to handle and illustrate large and complex datasets.

Mapping as Tool for Discovery

"It is through its pictorial representation and interactive analysis that modern network visualization gives life to many structures hidden from human perception, providing us with an original 'map' of the territory."[63] By mapping the collaborative writing process of a Wikipedia article, a stigmergic structure may be revealed along with patterns and indicators for further exploration and discovery. As explained by architect and theorist James Corner, the objective of creating a map isn't to convey a literal presentation of data, but rather to create an abstract *representation* of data, leaving enough room to work, explore and extract new insights that may not be detected otherwise. "The act of creating a map is a finding that is also a founding." [64] As Deleuze and Guattari exclaimed, "Make a map not a tracing!"[65] The objective is to use visualization not as a symbolic or metaphorical depiction, but instead as a tool for exploration and ultimate discovery. If the objective is to map the complex process of article emergence in Wikipedia (analogous to the trail of ants) and not just the outcome as depicted by the most recent version presented online (analogous to the single crumb), a new school of complex network mapping must be employed. As in many instances, the rise in technology has brought with it rising complexity, however it has also supplied the tools for analyzing it. With modern perspectives on graphical visualizations better suited for complex networks, and technologies at the ready for creating new visual depictions, the task of visualizing stigmergy in Wikipedia seems more opportunity than challenge. The Wikipedia database is rich with detailed information. This can actually act as a debilitating factor when too much information overwhelms and inhibits the ability to observe and understand. To avoid information overload, it is critical to determine the

[62] Warren Weaver, "Science and Complexity," in Manuel Lima *Visual Complexity*, 44.
[63] Lima, *Visual Complexity*, 79.
[64] James Corner, "The Agency of Mapping: Speculation, Critique and Invention," in Mappings ed., Denis Cosgrove (London: Reaktion Books Ltd., 1999), 213.
[65] Ibid.

objective of the desired map by defining a question the map is to answer.[66] In this case, the question is: how can the emergence of a Wikipedia article be visualized in order to create a platform for investigating stigmergy and indirect, collaborative interaction? In addition, a subset of questions may also be investigated once the map is in place. Namely: How does an indirect collaborative system handle conflict resolution in a productive way; and, How is vandalism, the Achilles heel of a collaborative system, handled in a way that an open system is preserved and protected?

About Trace

By using Processing,[67] a free and open-source programming language that enables the visualization of data, a new mapping tool by the name of Trace was developed in order to aggregate and graphically present the data exported from the English-language Wikipedia. Trace creates a complete map of a Wikipedia article based on its history from creation date to present day. It does this by pulling article data from Wikipedia and applying a number of relatively simple "rules" for building a graphic and interactive map. To create a map with Trace, the following Wikipedia data is used: article date, article size, author, author contribution size and any comments left as notes by the author. The following outlines the structure of the Trace map as well as the interactive capabilities critical for adaptively zooming in and exploring relationships and individual agents. With Trace, a correlation and causation between patterns, events and behavior can be explored.

Structure

The structure of a Trace map is based on a Centralized Ring,[68] (Figure 1) one of fifteen complex network maps as identified by Manuel Lima in his book, Visual Complexity.[69] One defining characteristic of a Centralized Ring is an elliptical center, which for the purposes of this project is used as a timeline, explained in further detail shortly. Shooting from the center of the structure outward are white edges representing the full length of the Wikipedia article at a

[66] Ben Fry, *Visualizing Data*, (O'Reilly Media: 2007), 3.
[67] Software downloaded from www.processing.org
[68] Lima, *Visual Complexity*, 158.
[69] Ibid.

specific point in time. The lengths of the edges are determined by the size of the article in bytes, which naturally grows as the article grows as more content is added over time. At the end of each edge is an ellipse, representing the size of an author's contribution in relation to the previous article size before a change was made. In cases when text is added, the ellipse color is yellow; in cases when text is deleted, the ellipse is white. (Figure 2)

Each revision is placed in chronological sequence from the elliptical timeline, in the style of "timepiece graphs", a terminology coined by data visualization artist Jer Thorp.[70] The elliptical timeline was chosen over a standard linear timeline because it serves a critical visualization objective: it allows for a representation of a much larger data set and therefore enables a clearer view of outlier behaviors such as vandalism or fluctuations in content length; instances which would not be visible on a linear timeline. This is especially relevant in vandalism cases where article pages are deleted in their entirety. While vandalism is an important element to be detected within the evolution of a Wikipedia page, it happens relatively less frequently than instances of relevant contributions. Should a linear timeline be used instead, the data set would require a "zoomed-out" view that would prevent an understanding of relationships between versions as they accumulate indefinitely. Because the article naturally grows over time, and therefore the center of the ellipse has less and less organic activity, the data presented in this area requires less space; whereas the external area of the map where the edges reach out, much more activities transpire and therefore more space for visualization is required. Unlike Thorp's timepiece graphs, Trace creates a gap between the start and end dates in order to emphasize that the map does not represent a cyclical process. (If the map started and ended at the same point, such an assumption may be more likely.) Based on a timepiece with a slight modification, an article's first revision and creation date are displayed at 3 o'clock and the last and most recent revision and date are displayed at 12 o'clock. The form of the Trace map is also reminiscent of the visualization created by Paul

[70] "Wanted: Prints That Visualize 20 Years of New York Times Stories," Fast Company CoDesign, accessed July 8 2013, http://www.fastcodesign.com/1663195/wanted-prints-that-visualize-20-years-of-new-york-times-stories

Otlet, the pioneer of information science, who created a map "Organization Mondiale" illustrating organization in his work Traité de Documentation.[71] (Figure 3) In Otlet's illustration however, the ¾ radial is used to illustrate a tree-based organization of knowledge rather than a network.

Interactivity

Interactivity with the map is an important element in transforming the visualized output from aesthetic representation (an allusion to Deleuze and Guattari's "tracing") to a mapping tool for research and exploration. By interaction with the map, a deeper understanding of the collaborative process can be extracted. The following interactive tools invite autonomous, proactive exploration of the collaborative Wikipedia writing process.

- *Scale*

Adaptive zooming reveals information and relationships per scale. By zooming in from a macro to a micro view, the tool enables three fundamental perspectives for analyzing complex networks:[72] *Macro analysis*, *Relationship analysis*, and *Micro analysis*. (Figure 4) Macro analysis makes it possible to detect patterns. It directs the eye within a vast data set to points of interest for further investigation. Relationship analysis reveals relationships between revisions. This is where interactions between different collaborators can be researched. Micro analysis offers perspectives on individual authors, their level of involvement and their motivations for submitting revisions.

- *Animate*

While the static view allows for a macro or micro snapshot of Wikipedia history, an animated view over time shows the interactive process played out over history. This capability is especially insightful when seeing where the collaborative process is gradual and when a comparative "slowing

[71] Paul Otlet: Trait' de documentation, 1934, s420, (presentation by Frank Harmann, Total Recall Symposium Session 3, Ars Electronica Festival, Linz, Austria, September 8, 2013).
[72] Lima, *Visual Complexity*, 91.

down" or "speeding up" occurs (potentially indicating disputes, vandalism, edit wars or significant current events at a point in time).

- *Manual Review*

A new "Start Point" can be set for the purposes of zooming in and manually exploring singular changes as they transpire in sequence, one after the other with the "Previous Revision" or "Next Revision" buttons made available in the player. This allows for a deeper micro analysis over time, understanding of the relationships between each contributor and evaluating when exactly a significant change transpired in the article's history.

- *Multiple Map Comparison*

Trace also makes it possible to view several maps in the same view, thus allowing for a comparison of the shape of different Wikipedia terms simultaneously. This view is useful in exploring potential relationships across different terms in similar or differing fields.

Once the complete history of a Wikipedia article is assigned a visual form, the naked eye is able to quickly locate points of interest for further investigation. This ability is best described by Gestalt psychology and the Gestalt laws of grouping, where relationships between objects are inferred based on their shape or location in relation to each other.

Trace Map - Inner Patterns

"Gestalt" is a German word for form, shape and configuration.[73] In the English language, it is used in reference to "wholeness";[74] viewing a subject in its entirety rather than the elements that create it. Gestalt psychology was first introduced in the beginning of the 20th century and primarily focuses on exploring the cognitive tendencies of sight

[73] Gerald Westheimer, "Gestalt Theory Reconfigured: Max Wertheimer's Anticipation of Recent Developments in Visual Neuroscience," *Perception*, 1998, 28, http://www.trincoll.edu/depts/ecopsyc/courses/westheimer_gestalt.pdf, 1.
[74] "Gestalt," Wikipedia, accessed August 5, 2013, http://en.wikipedia.org/wiki/Gestalt.

and perception.[75] Through the 1930s and '40s[76] eight Gestalt laws of grouping were defined, listing types of groupings determined by certain conditions. Using Gestalt laws of groupings, initial points of interest on a map can be identified immediately with the naked eye. Herein lies the core motivation for creating a graphic map: with a graphical form, sight can be used as a means for identifying significant events of synergy or friction within the stigmergic medium. Moreover, in cases where characteristics of group formations are repeated, taxonomy of design patterns may be inferred for purposes of "reading the map" and extracting new meaning and significance attributed to human behavior. With these new patterns a new dimension of research is available for conjecture in the exploration of human stigmergy.

By combining the ability to adaptively scale Trace maps with the utility of Gestalt grouping laws, it is possible to detect the emergence of patterns within the macro and micro perspective and correlate such patterns to significant events, human behavior and the resilience of a collaborative environment. "It is in the patterns of relations, or in 'gestalts,' that the receiver finds the meaning, and not in the individual signs for and in themselves."[77] The Trace patterns mentioned below are a first attempt at identifying and inferring potential meaning from visual markers. Gestalt groupings used include: Gestalt law of Proximity; Gestalt law of Similarity; and Gestalt law of Continuity. (Figure No. 5) Each pattern includes a visual description and an inference for what the pattern may indicate. Additional research and exploration is required to establish clear and unequivocal design pattern taxonomy. Moreover, because Wikipedia behavior is considered non-finite state,[78] it continues to generate new patterns for discovery. Therefore Trace maps should continue to be explored in order to also catalog new patterns not mentioned below.

Hypothesized Patterns

[75] Roy R. Behrens, "Art, Design and Gestalt Theory," Leonardo Vol. 31, No. 4, (1998), 2.
[76] "Gestalt Laws of Grouping," Wikipedia, accessed August 5, 2013, http://en.wikipedia.org/wiki/Gestalt_psychology#Gestalt_laws_of_grouping.
[77] Kazmierczak, *Design as Meaning*, 47.
[78] "New Clues to Wikipedia's Shared Super Mind," Santa Fe Institute, accessed August 24, 2013, http://www.santafe.edu/news/item/dedeo-wikipedia-shared-super-mind/

- **Significant Event**: visually identified by clusters of dots within close proximity to one another or by areas of bright white edges. When such a visual pattern emerges, it may be inferred that considerable effort (comparable to the status quo) is being made either by one or many agent(s) in a specific span of time. This may indicate a significant event within the evolution of a Wikipedia term, or may be correlated to events transpiring in the non-virtual environment, for example a war, a law being passed, a natural event. In either visual scenario, both are easily identified and invite further exploration by zooming in and investigating the changes made, the contributing author and the timestamp. (Figure 6)

  - **Edit War**: An edit war occurs between two editors who revert back and forth to their initial version up to 3 separate instances, each. An Edit War pattern is visually identified by the triple repetition of a pair of the same-sized ellipses (one yellow, one white), sequential proximity on the timeline, one situated above the other. (Figure 7)

- **General Consensus**: visually identified by instances when the growth of an article over time remains at a constant state, either creating a plateau within a designated area or a steady growth. It may be inferred that this pattern reflects consensus during this timeframe, since the article does not experience dramatic changes, disputes or vandalism. (Figure 8)

- **Deliberation**: visually indicated by a "dip" in the shape of the map creating a concave cavity over a period of time, followed by a re-growth of the article length. This may indicate when varying perspectives are being contributed, reflecting a "heated discussion" surrounding a specific topic within the article page. In these instances, it may be worthwhile to investigate further in the Talk Page, an additional source of interaction available in each Wikipedia page, accessed through a tab next to the View History tab. (Figure 9)

- **Stable Jump**: visually depicted by a new and *higher* plateau in the map's topography which remains intact and creates a new baseline for contributions that follow. This pattern may indicate a synergetic contribution to article content that is "accepted" by the contributors and remains intact over time. (Figure 10)

- **Stable Drop**: visually depicted by a new and *lower* plateau in the map's topography which remains intact and creates a new baseline for contributions that follow. This pattern may indicate that an entire section of the article was removed to form an entirely new and independent article. This is an especially stigmergic event in that one article eventually prompts the emergence of an entirely new article. (Figure 11)

- **Outliers**: visually identified by yellow or white ellipses significantly larger or smaller than those preceding or proceeding them and disproportionately distant from the article length "path", either outwardly or inwardly. Those versions that remain singular and are unable to disrupt the shape of the map as a whole can be considered outliers since their contribution was not a catalyzer for more or less text to the article. (Figure 12)

- **Terminal Vandalism**: visually identified by white ellipses situated at the center of the map on the map's timeline. These visual markers indicate that the entire article page was deleted, most likely intentionally. This is especially evident in cases where white ellipses are repeatedly situated on the timeline. In all cases, the pattern of white ellipses at the center is immediately followed by yellow ellipses of the identical size, which represent reversions of the severe deletions. (Figure 13)

Trace Map - Outer Patterns

Generally speaking, a spiral-shape can be considered the foundation for the shape of every map, since by design the timeline is circular, the first and last edges consistently start and end at the same respective point on the map's timeline, and the size of the edges can be expected to grow in length over time due to the stigmergic engines promoting more content. However, interpersonal interaction is a significant factor in the non-finite nature of the article generation process.[79] If this is the case, it is to be expected that each Trace map shape should contain sporadic and unique fluctuations on its timeline reflective of "organic", turbulent and improvisational interactions between agents. Or in other words, when the shape of a complete map reveals a growth incline with mathematical precision, this may indicate a finite-state editing process reflective of control hierarchy interference. Such instances may be explained by the involvement of technological interference in the form of bots which are programs that have the ability to make automated changes to an article; or protections imposed on an article restricting an entirely open collaborative process (oftentimes an administrative response to high frequencies of vandalism).

Bots are mostly automated programs approved by a supervising Wikipedia committee and used to help maintain the over 30 million pages of the English Wikipedia.[80] The bots are assigned specific tasks such as reverting vandalism, detecting conflict-of-interest editing, or even italicizing article titles. Changes by bots are made automatically to article texts and are intended for mostly mundane tasks.[81] By definition, bots are non-human and therefore non-collaborative elements within the Wikipedia system. This means that their involvement in the article editing process may affect the natural stigmergy mechanism and ultimately the emergence of a Wikipedia article. Although assigned to execute mostly simple tasks, if incorrectly designed they have the power to significantly disrupt the Wikipedia environment.[82]

[79] DeDeo, *Evidence*,7
[80] "Bots," Wikipedia, accessed August 21, 2013, http://en.wikipedia.org/wiki/Wikipedia:Bots.
[81] Ibid.
[82] Ibid.

Wikipedia is mostly open to public contributions, yet the level of openness is determined by a hierarchy of 8 levels of article protection.[83] Articles with a high likelihood of repeat vandalism are assigned "Protected" status, which means restrictions are imposed, openness is reduced, and less people can contribute.[84] Editing permissions are afforded to contributors based on their involvement, history and credibility within the Wikipedia system. The lowest and open levels of permission allow anyone with an IP address to make revisions, next permission levels require that to make a contribution one must have a Wikipedia account, while the most highly protected articles can only be changed by staff members of the Wikimedia Foundation. This method of restriction is especially important in helping to protect topics that are controversial and attract a lot of damaging vandalism. However, though their value is undisputed, they are also founded on a control-hierarchy mechanism which means they also naturally interfere with the open and public collaborative process.

With these two "non-human", hierarchy-driven mechanisms in place to maintain, manage and protect Wikipedia, the organic emergence of an article may be severely affected. In this case, it is worthwhile to investigate whether such instances can be seen through Trace maps when observing: the complete and whole shape of a singular map; and the similarities between maps, detected when several maps are simultaneously compared in one view. Initial patterns in these cases may include the following:

- **Organic Turbulence:** visually identified by inconsistent lengths of the edges in the micro-level but emitting a trend of overall growth. This pattern may indicate organic, human-generated interaction reflective of the dynamics of collaboration. (Figure 14)

- **Rigid Growth**: visually identified by a level of visual precision in the edge growth over time. This pattern may indicate the involvement of technological interference in the form of bots or restrictions imposed due to an article's protected status.

[83] "Protection Policy," Wikipedia, accessed August 21, 2013, http://en.wikipedia.org/wiki/Wikipedia:Protection_policy.
[84] "Protection Policy."

(Figure 15)

- **Map Correlation**: visually identified by a similarity in shape of two or more maps (different terms). If maps in the same field of interest are identically shaped, this may be attributed to specific drivers, whether technological or human, attempting to take control over a field of terms, or that the similarities can be attributed to historical events affecting a specific and correlated field of terms. In this case, such a pattern would be within the realm of organic human-driven interaction impacted by a global event and should not be attributed to hierarchic mechanisms. (Figure 16)

From the research perspective, when articles are identified as having high involvement of bots or protection restrictions, or both – this may create additional opportunities for investigating a number of questions including: Why do certain articles exhibit patterns of centralized control, while others do not? How does the technical interference affect emergence within a human interactive environment? And, Do such centralized control mechanisms (intended to benefit the system) enable or inhibit the human stigmergy process?

Trace Map as Research Platform

As an interactive tool recording the collaborative process of knowledge-making within Wikipedia, Trace offers a new platform for researching a wide range of disciplines. Three mentioned in this paper include: epistemology, conflict management & resolution; and Global Brain research.

Epistemology & Knowledge-Making

In Wikipedia, the collective discourse eventually defines the scope, meaning and significance of a term. Yet if this discourse was isolated from the global perspective it would have very little impact. Through the global reach made possible by the web, Wikipedia has become such a popular website that it is top-ranking in search engines for

a wide range of terms[85] and in some cases, quoted verbatim in Google's glossary tool.[86] Through its popularity, Wikipedia has become a powerful platform in defining knowledge. Therefore it is reasonable to infer that the discourse taking place within Wikipedia is a process of knowledge-making. However, it is important to note that the terms and their respective history are *representations* of truth, rather than an ultimate and unquestionable truth. They serve to present a perspective of a collective group of authors at a specific point in time. In Michel Foucault's "The Archeology of Knowledge," Foucault criticizes the illusion of a clear and cohesive recording of history and instead argues that discourse in and of itself has a much greater impact than the meaning and significance extracted from it. "The highest truth no longer resided in what discourse *was*, nor in what it *did*: it lays in what was *said*."[87] Power lies not in the last version of a Wikipedia term, but in the discourse that created it. With Trace, this genealogy of a term takes shape, showing a historical "paper-trail" of total revisions made in time and making it possible to investigate the discourse that defines the term.

Foucault also explains a tendency to see an author's active participation as an infinite resource of generating discourse, however he warns that it is also important to take note of the restrictive and constraining role authorship may have within discourse.[88] With each authored revision, Wikipedia requires informative data including the author's name (or IP address), thereby also recording the geo-location from where the revision was submitted. Recording such demographic information is useful in evaluating whether an article is dominantly controlled by a specific author or a specific geographical location. Moreover, an awareness of which countries are underrepresented in the Wikipedia authoring process is also important in evaluating which countries show tendencies for dominating knowledge as it is recorded and perceived, and which countries are excluded from the discourse, therefore rescinding their power. For example, while Wikipedia is open and collaborative, if citizens of less technologically advanced

[85] Sam Silverwood-Cope, February 8, 2012, blog post "Wikipedia: Page one of Google UK for 99% of Searches," *Intelligent Positioning Blog*, accessed September 1, 2013, http://www.intelligentpositioning.com/blog/2012/02/wikipedia-page-one-of-google-uk-for-99-of-searches/

[86] In Google, it is possible to request the definition of a word by typing it in after first typing "Define: [sample word]". Google uses a variety of resources including the Merriam Webster Dictionary, however Wikipedia is presented in high frequencies.

[87] Michel Foucault, "The Archeology of Knowledge and the Discourse on Language," trans. A.M. Sheridan Smith (New York: Pantheon Books, 1972), 218.

[88] Foucault, Archeology, 224.

countries do not contribute revisions at the same pace as others, more economically developed ones - they are less likely to be active participants in the Wikipedia writing process and therefore in the process of making knowledge and recording a dominant form of history. This circumstance has political implications on the global scale.

A means of evaluating global perception of truth and history-making is to juxtapose the transpiring of current events on a Trace Map. (Figure 17) By comparing the evolution of a specific term with related events, causation and correlation between events and Wikipedia content can be explored. For example, how do historical events act as triggers for stigmergy within a particular term? Do specific events promote heightened activities of revisions and vandalism or a "pause" in activity? If so, which do, which do not, and why is this so? Trace brings to light the collaborative process of an article so that such questions and more can be investigated.

Conflict Resolution

When content is in dispute, discussion and mediation are initiated until a version "agreeable enough" emerges. In cases when topics themselves have conflicting perspectives, the collaborative process will eventually converge into a balanced perspective where both sides of the issue are presented as definitive characteristics of the term.[89] What supports this accurate and useful output is an editing platform allowing cooperative human interaction.

Wikipedia's mandate is to offer a "most objective" reference of knowledge. This can be challenging when the system is public and completely open to all, amateurs and professionals, vandals and advocates alike. However, with stigmergy, the advantage of externalizing information into the medium[90] allows individual and collective information processing, prompting continued improvements and "repairs" until the outcome reaches a level of stability. Every new article or change made to the site is an invitation for review and scrutiny by the same or different agents. When issues or problems are detected, editors can react by resolving or opening a discussion in the article's "Talk" page. Additionally, "reversions capture implicit cases of task conflict, which are strongly

[89] Heylighen, *Accelerating*, 16.
[90] Heylighen, Vidal, *Getting Things Done*, 17

associated with the boarder phenomenon of relationship conflict."[91] With time, the stigmergic interaction leads to an emergence of credible content. Because connectivity on the Wikipedia network is high, and because each change on the shared medium affects all agents,[92] there is always a growing pool of potential agents available to review, edit, monitor and improve article content.

A complex system coordinates the activities of different agents in order to minimize friction and maximize synergy.[93] Wikipedia and the collaborative article writing process is one such an example. Friction can be represented by conflicts, disputes and vandalism; synergetic changes can be attributed to edits deemed agreeable and helpful, as indicated by their ability to withstand repeated changes over time; minor changes relating to grammar or syntax can be considered neutral. The perpetual process of submitting revisions until eventually mostly acceptable contributions remain in place and poor, inaccurate or unfounded ones are removed create a coherent coverage of a particular term.

Wikipedia coordinates individual activities of agents with the objective of reducing friction and maximizing synergy. It spontaneously evolves towards what is referred to as an *attractor*: "a stable regime of activity towards which the system will tend to return even if disturbed."[94] Through contributions and interactions over time, Wikipedia articles emerge and evolve. When content reaches a level of maturity and consensus, it reaches a level of stability. Stability, not permanence, as any text can always be changed at a future time by anyone. This implies that friction in the form of conflicts and disputes play an important role no less than synergetic contributions, in fostering the growth and convergence of a Wikipedia article. "In turbulence is the preservation of the world,"[95] so is the case with Wikipedia. Without the ongoing disputes and interactions, Wikipedia would stagnate, lose its credibility, and in a metaphorical sense, die. The legitimacy and value Wikipedia strives to achieve is supported by the fact that so many people are involved in the process, testing it, pushing it, disturbing it and even vandalizing it. Although Wikipedia has an attractor pushing towards general consensus,

[91] DeDeo, *Evidence*, 3
[92] Heylighen, *Accelerating*, 10.
[93] Ibid, 22.
[94] Heylighen, *Self-organization*, 4
[95] Kelly, Lloyd, *Bootstrapping*, Location: 3026

because the world around us is always in flux, the content is also always in motion, always at risk of changing.

From "Paper Clip" to "Palestine", each article within Wikipedia is the outcome of a collaborative process of interactions, feedbacks, discussions, disputes, edit-wars and vandalism. Through visualization it is possible to see how disputes and consensus manifest within a collaborative environment. Especially in cases of heavily disputed topics, Trace can be used to research how conflict is handled in an indirect and open environment. It can help to more accurately define the specific elements of dispute and can also be used to shed light on issues that are in agreement, a primary foundation from which to work towards resolution of conflict.

Wikipedia as Global Brain

Through stigmergy, the passive Wikipedia medium eventually takes on a new role as mediator, eliciting and directing the agent's actions.[96] What emerges is collective intelligence where the process of coming together as a collective is more powerful than any individual approach.[97] This idea of collective intelligence distributed across the globe may also be referred to as a Global Brain,[98] or nervous system for the Earth where thoughts and ideas are contributed by the individual and knowledge is perpetually generated and openly shared with the collective. In his book "The Wisdom of Crowds", James Surowiecki outlines a list of requirements for collective intelligence. They are: diversity of knowledge and experience; independence among individuals; decentralization or division of labor; and aggregation which relates to the ability to converging diverse thought into a cohesive and collective definition.[99] The Internet has been identified as a Global Brain, however challenges in optimizing the potential of a Global Brain relate to establishing mechanisms for managing communication and interaction.[100] By reviewing Wikipedia's stigmergic and non-finite state characteristics, its successful qualification of Surowiecki's collective intelligence requirements, as well as its success in intelligently managing communication and generating a collective

[96] Heylighen, *Accelerating,* 23
[97] Heylighen, *Self-organization,* 1
[98] Heylighen, *Accelerating,* 13.
[99] Heylighen, *Self-organization,* 11.
[100] Heylighen, *Accelerating,* 13.

intelligence with every saved revision – it appears Wikipedia may be a useful case study in addressing this challenge. Specifically, by using the visual properties of Trace maps additional perspectives may be explored in pursuit of identifying which communication mechanisms support the growth and development of a Global Brain.

Further Research

As Wikipedia is a vibrant and complex system, it offers many areas for further research and exploration. Trace creates a visualization of data in order to create an interface for research and exploration on a variety of topics. The patterns listed previous, as well as the general areas of research are initial impressions from this new tool. By use of an interactive map, it is possible to start asking meaningful and "site-specific" questions relating to collaboration, stigmergy, knowledge-making and more. Additional questions relating to the classification of authorship and article types; stigmergic triggers; and collaborative resilience are additional directions for further research. Continued exploration will help answer the following questions:

1. *Authorship Classification*: Are there classifications for types of editors? (Active but contributing small edits; seldom but contributing significant edits; vandals; argumentative; antagonistic; or people who act as stigmergic triggers by evoking many others to contributions etc.)

2. *Article Classification*: Is the pattern for an article unique or redundant across articles? Are there classifications of article types based on their pattern of emergence? Is there a tipping point in terms of time, author diversity, or contribution frequency for the maturity of an article?

3. *Stigmergic Triggers*: Which articles act as triggers for other articles, or in other words, which articles act as stigmergic engines within the Wikipedia platform as a whole? Additionally, what are the triggers that promote or constrain a human stigmergic mechanism?

4. *Balancing Stigmergy with Hierarchy*: How much are articles organically collaborative and when do they become controlled? How are hierarchic control and collaborative freedom balanced within a human collaborative environment, and how can this balance be preserved over time?

Conclusion

The human social environment has become more connected, more interdependent and therefore more complex.[101] A surge in technological development and an openness of information made possible by the Internet have led to paradigm shifts in how we view our world and how we operate in it. Meanwhile, a rise in complexity is challenging and disrupting the very structure and dynamic of our human civilization, rendering many if not most hierarchical, top-down organization structures flawed at best and obsolete at worst. From the self-regulating mechanism in markets to resource management in traditional communities, social systems have been recognized as having the ability to perform equal to or oftentimes better than engineered, top-down, hierarchy-controlled systems.[102] This paper presented stigmergy as a self-organizing mechanism, and demonstrated its effectiveness in accomplishing complex tasks. Next, shortfalls in control-hierarchies were presented to make the case for the timely relevance in exploring alternatives to top-down organization.

By exploring bottom-up, self-organizing, stigmergic systems, it may be possible to discover alternative ways to organize people, collaborate and accomplish shared goals. Wikipedia was chosen as one such environment, a platform that serves as a medium for communication and a trigger for constant and indirect collaboration and content-generation. In order to cope with the overwhelming data available and transform it into meaning, a visualization tool was developed for the purpose of giving form to a process and offering an initial attempt at correlating patterns with human behavior, events and tendencies. Through Trace maps, design can be used as a new frontier for researching human stigmergy and related areas of interest.

101 Bar-Yam, *Complexity*, 1
102 Dedeo, *Evidence*, 1

List of Figures

Figure 1: Centralized Ring

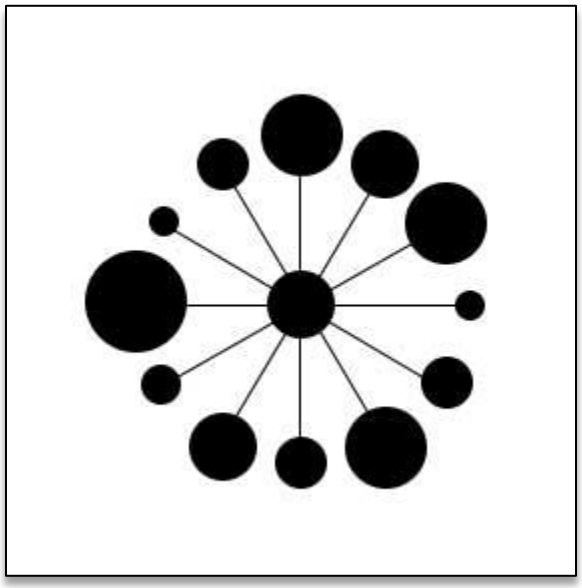


Figure 2: Trace Map Key

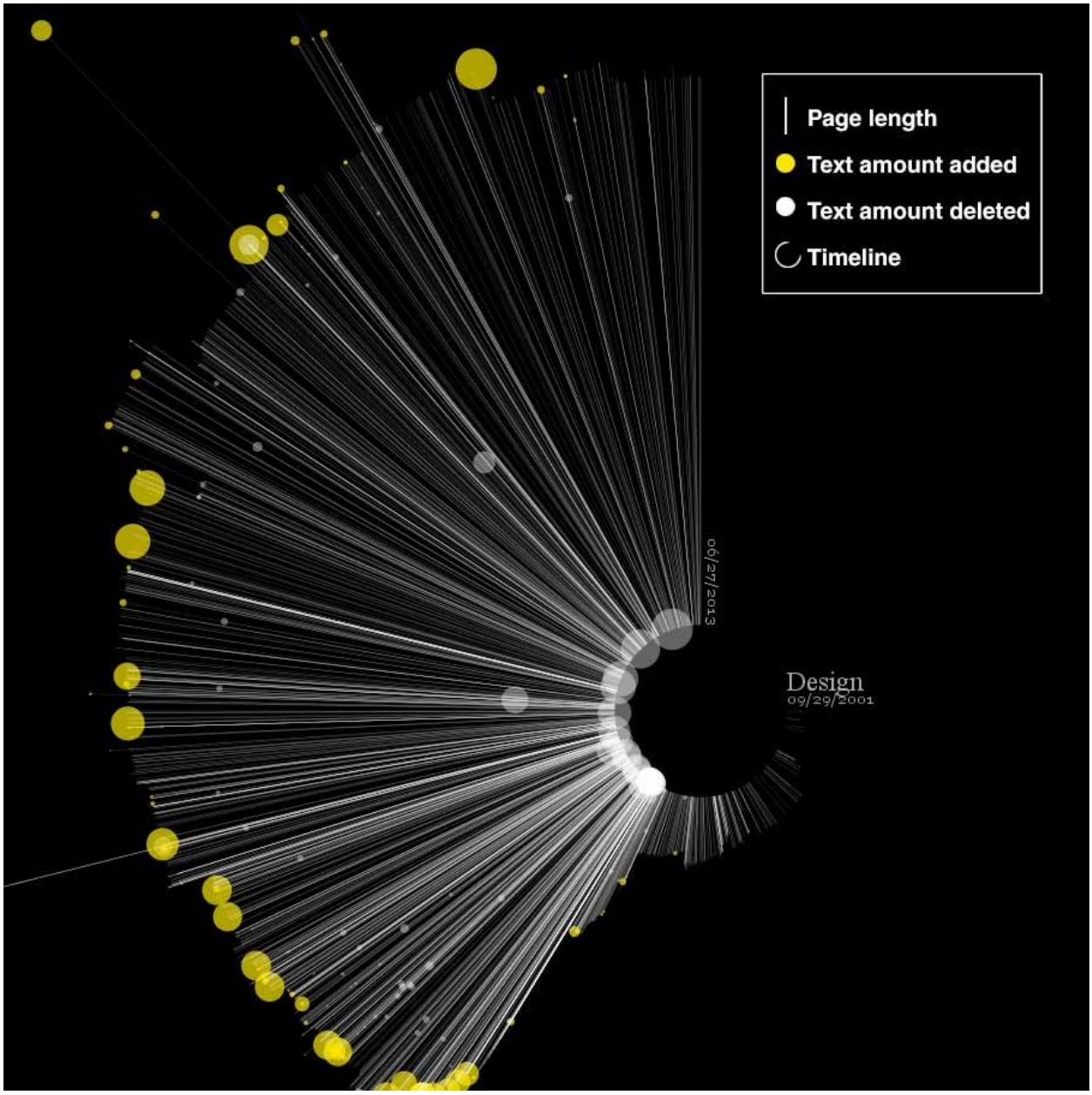


Figure 3: Paul Otlet's Organisation Mondial

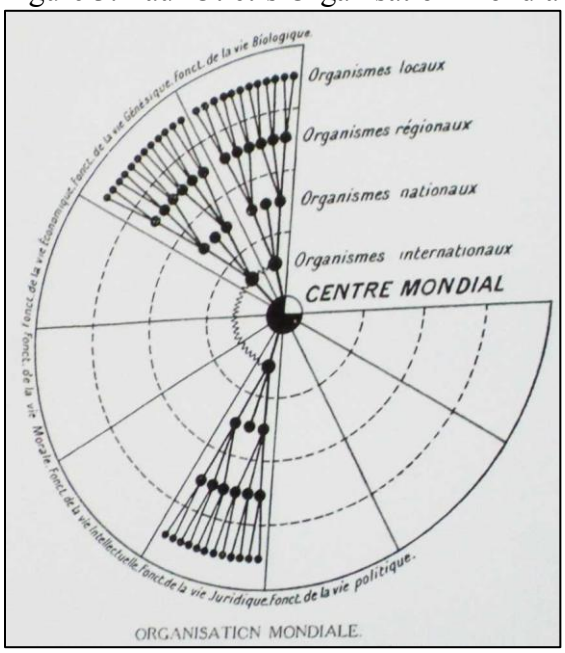


Figure 4: Three critical views of network visualization

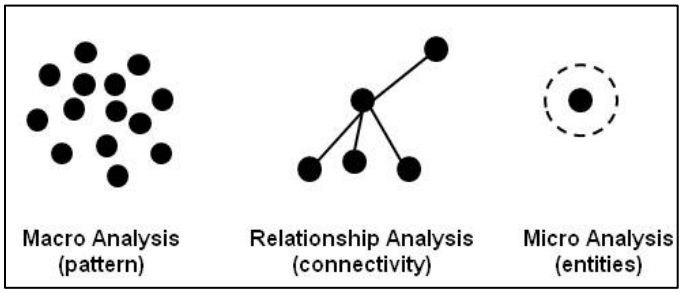


Figure 5: Gestalt Laws used to identify Trace Patterns: Proximity, Similarity & Continuity

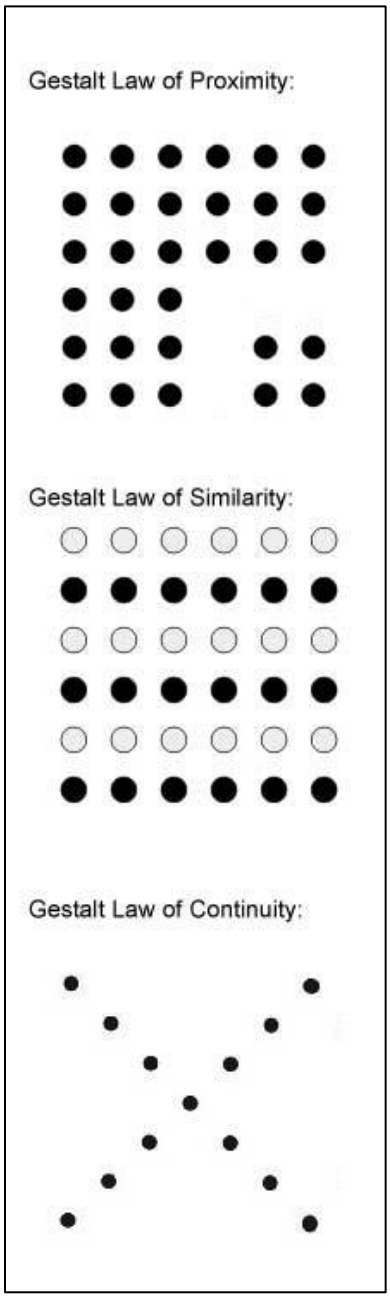


Figure 6: Pattern, *Significant Event*

Figure 7: Pattern, *Edit War*

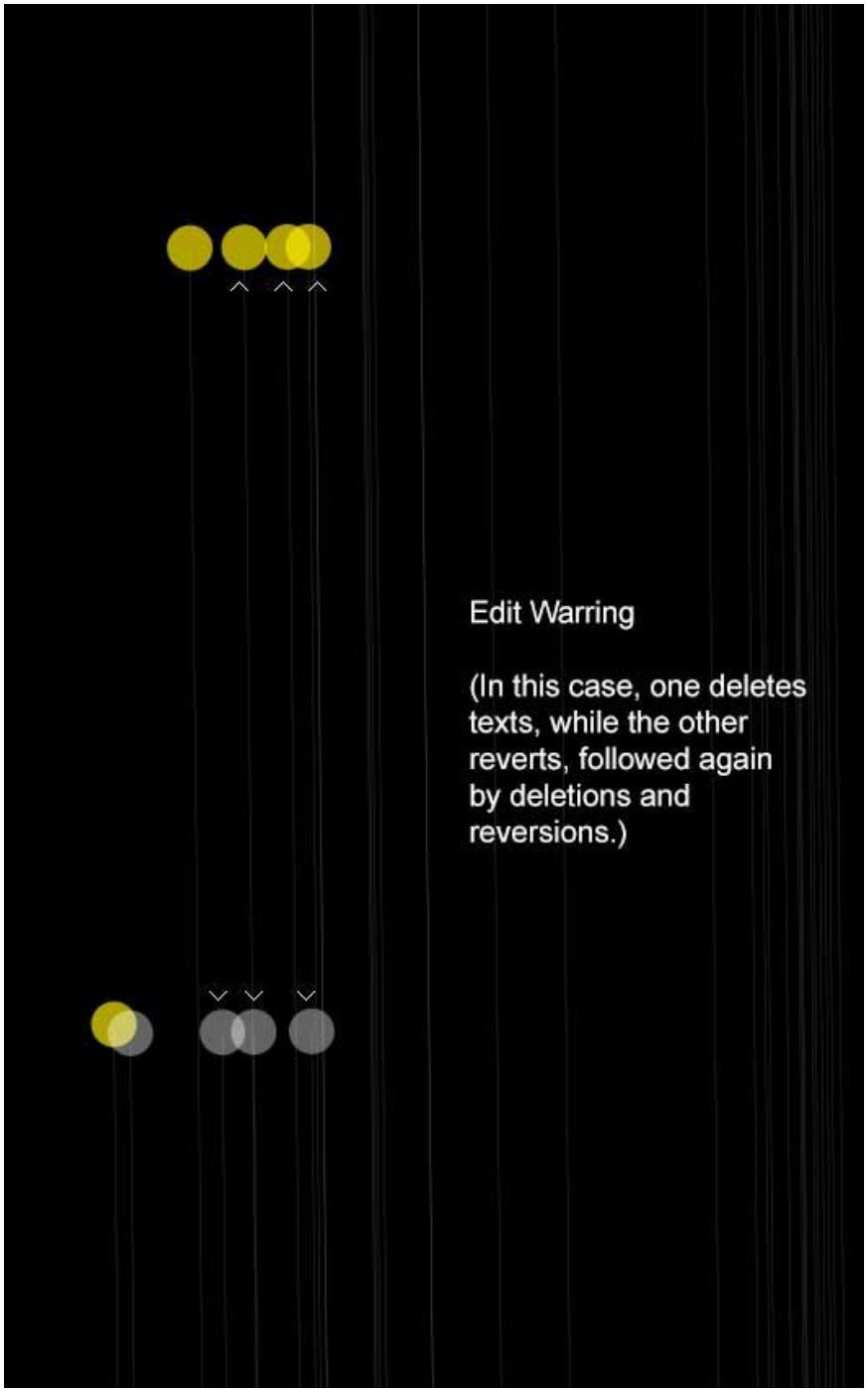


Figure 8: Pattern, *General Consensus*

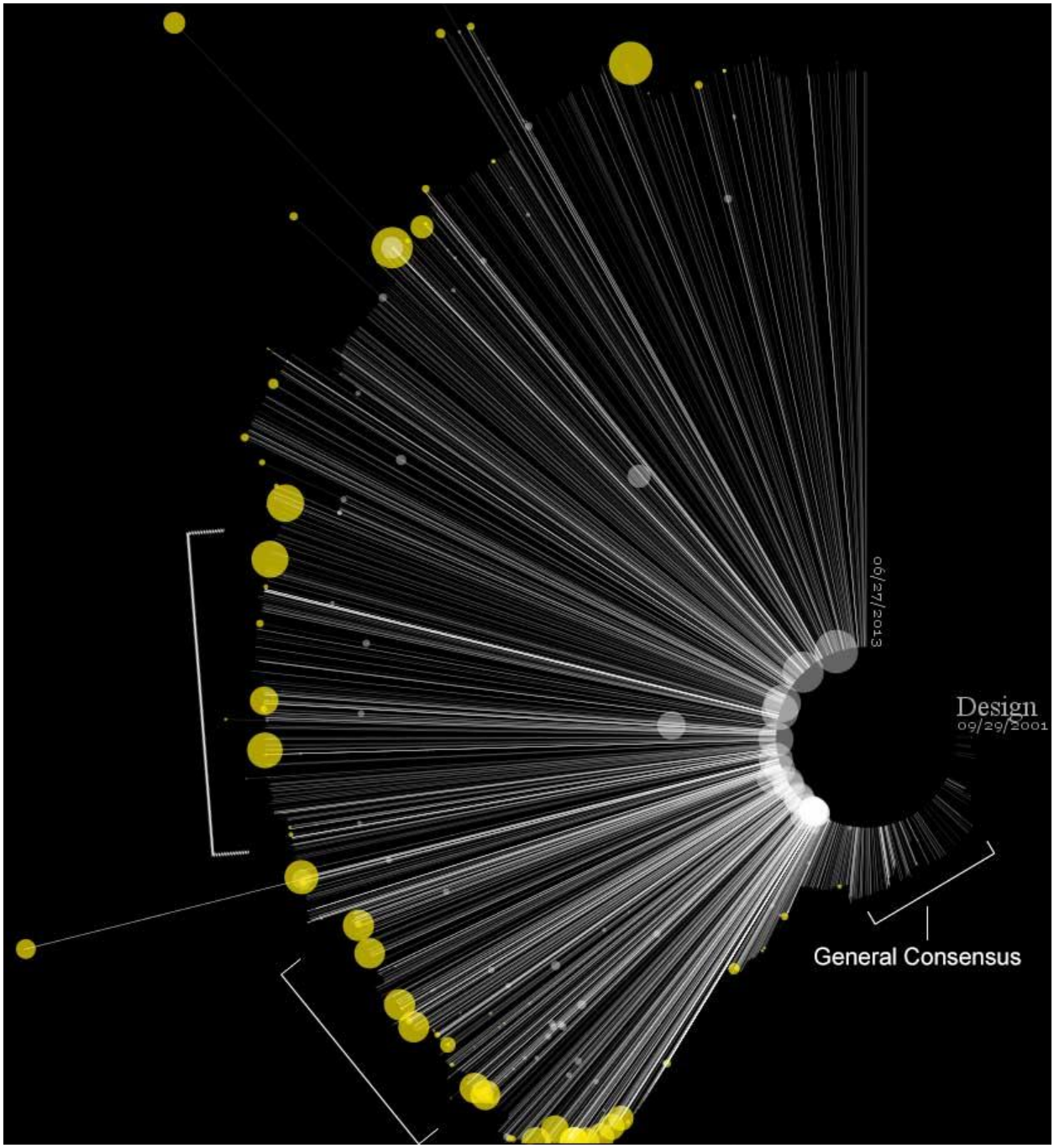


Figure 9: Pattern, *Deliberation*

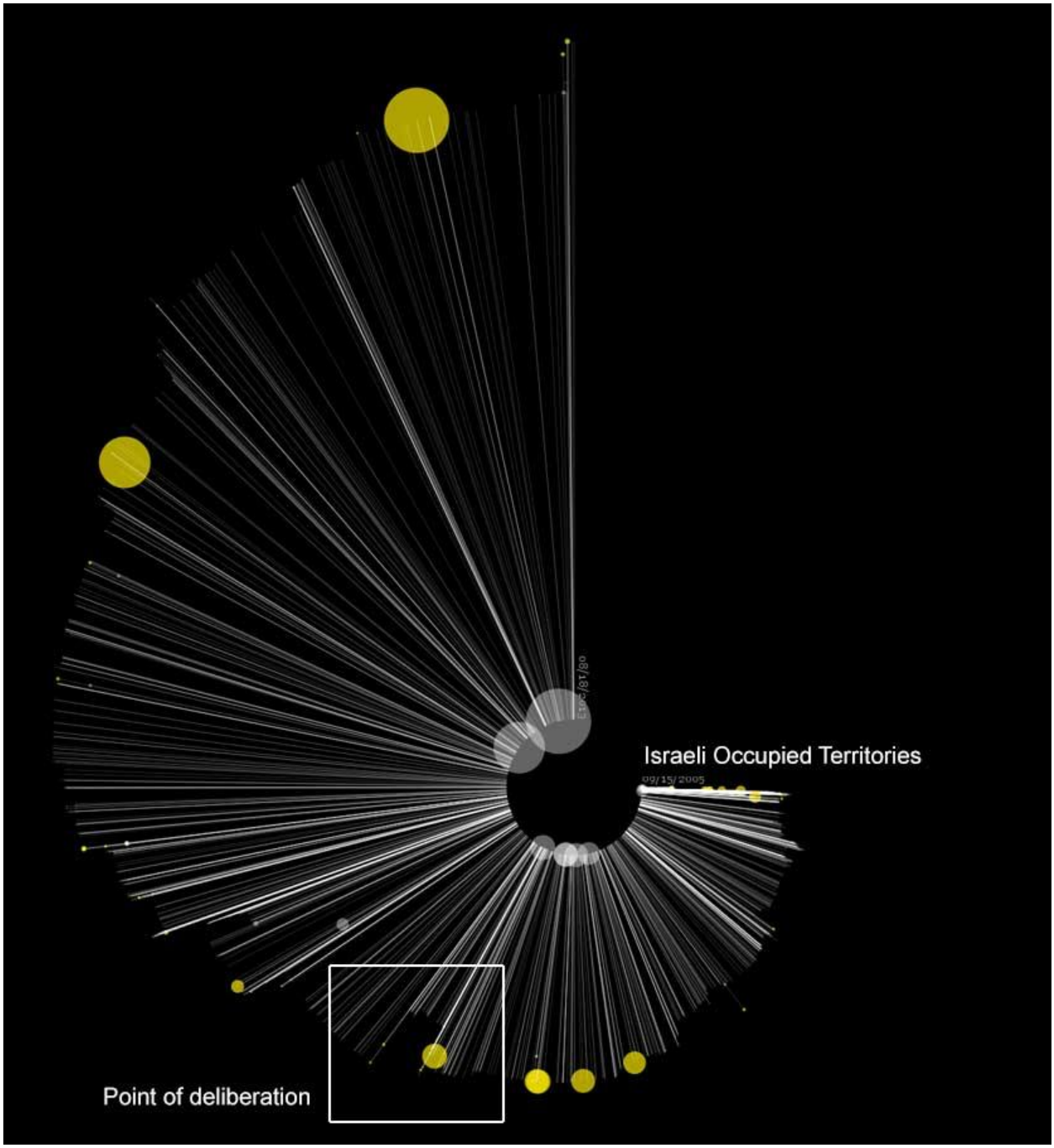


Figure 10: Pattern, *Stable Jump*

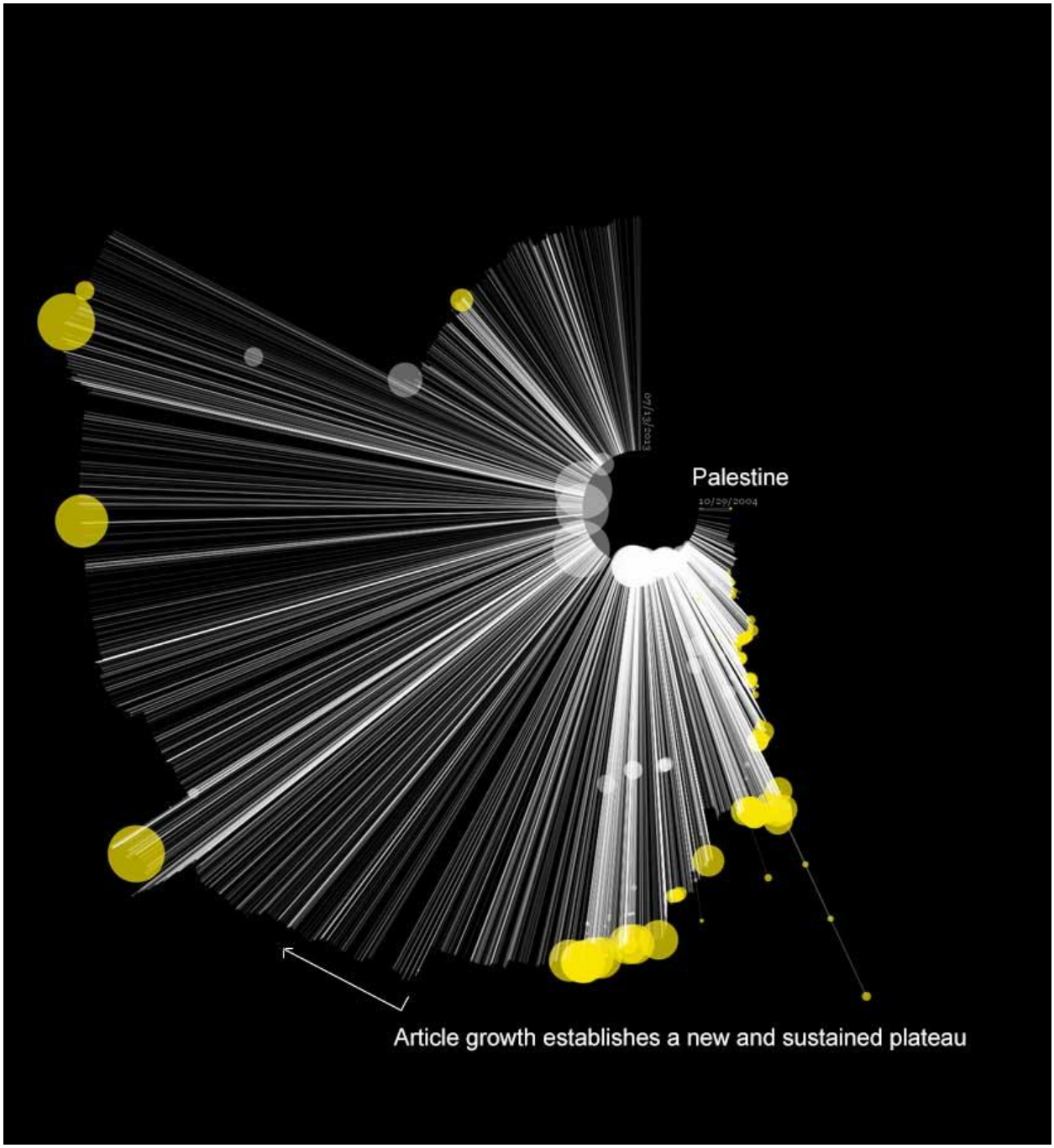


Figure 11: Pattern, *Stable Drop*

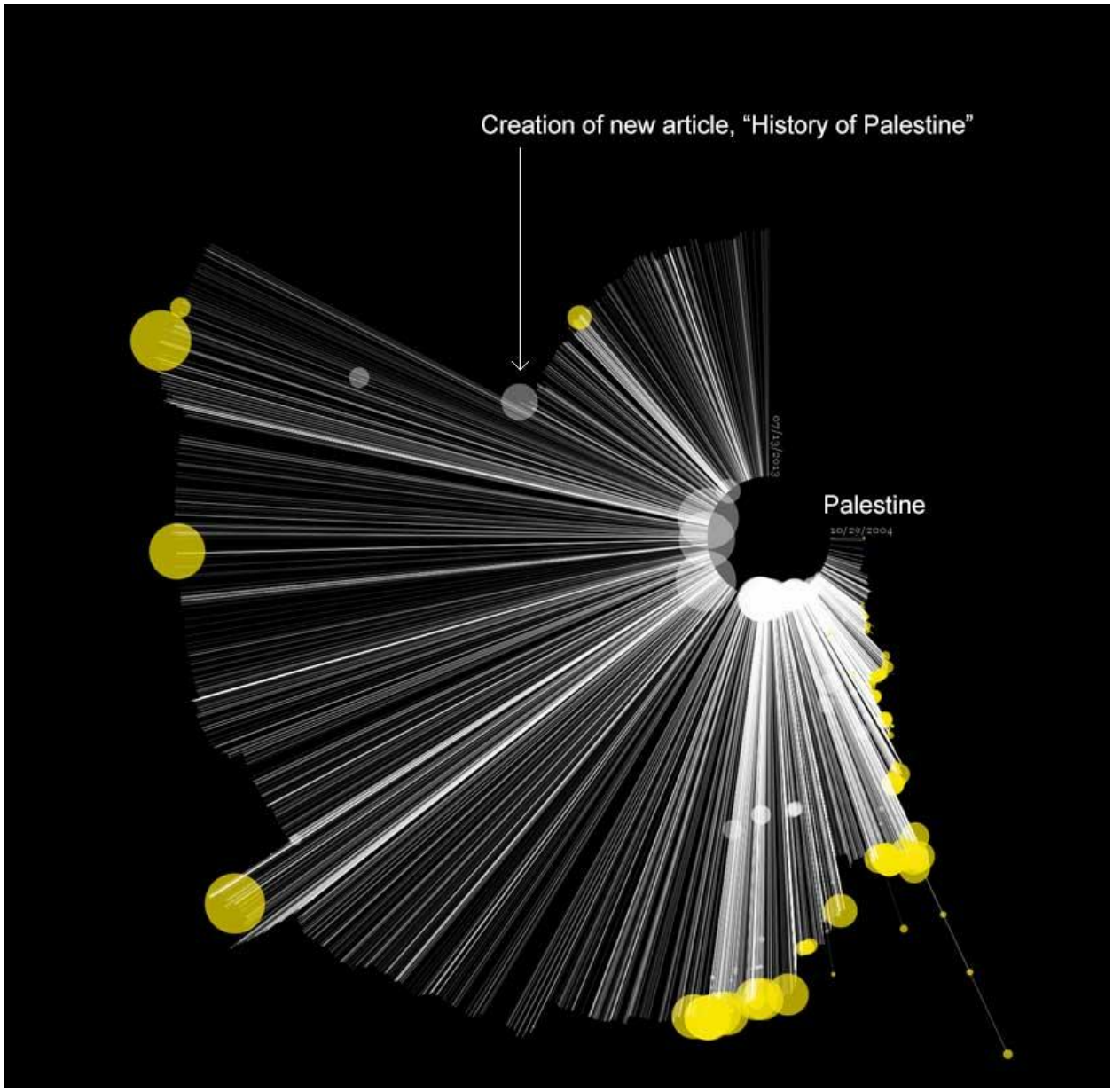


Figure 12: Pattern, *Outliers*

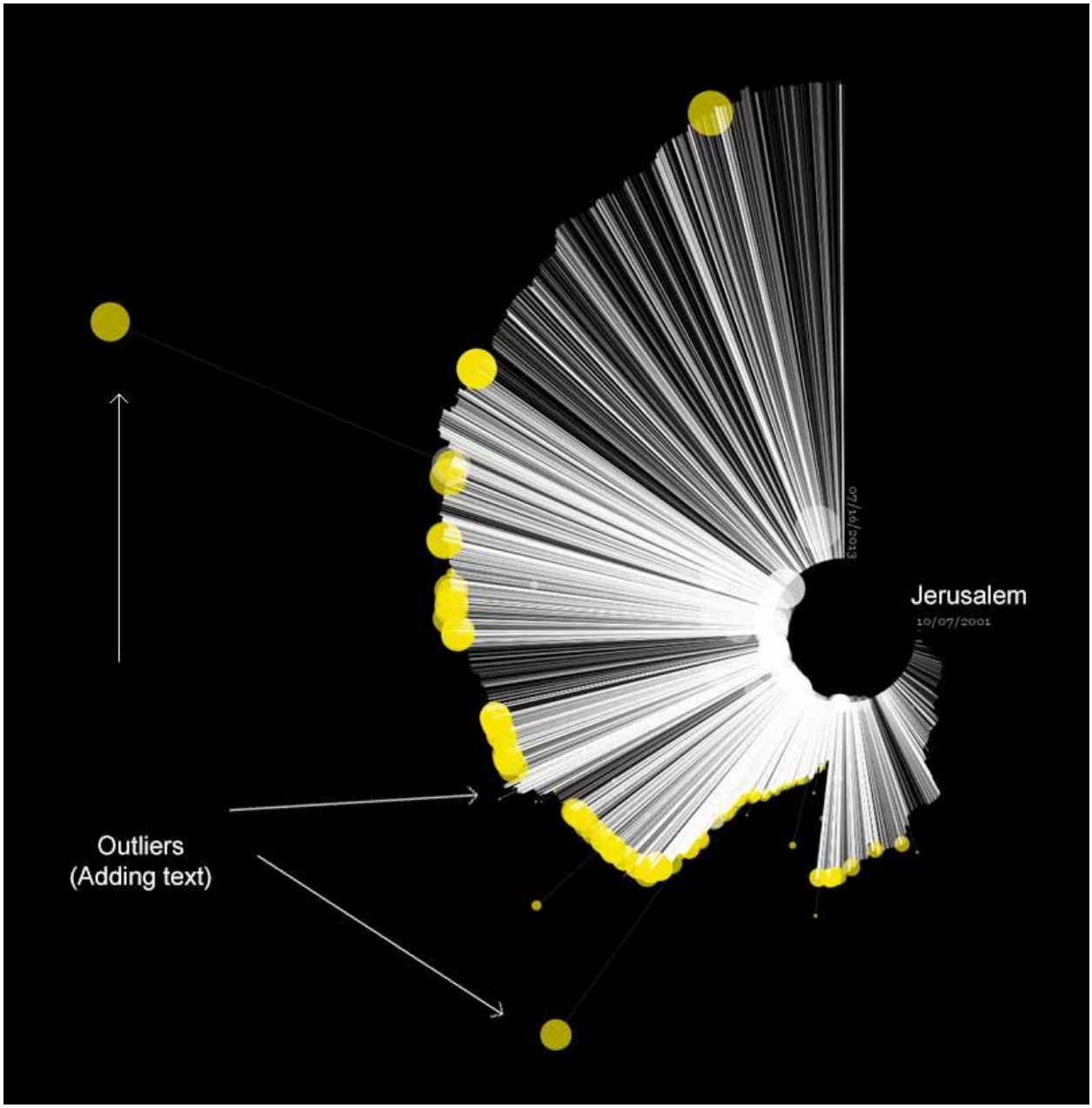


Figure 13: Pattern, *Terminal Vandalism*

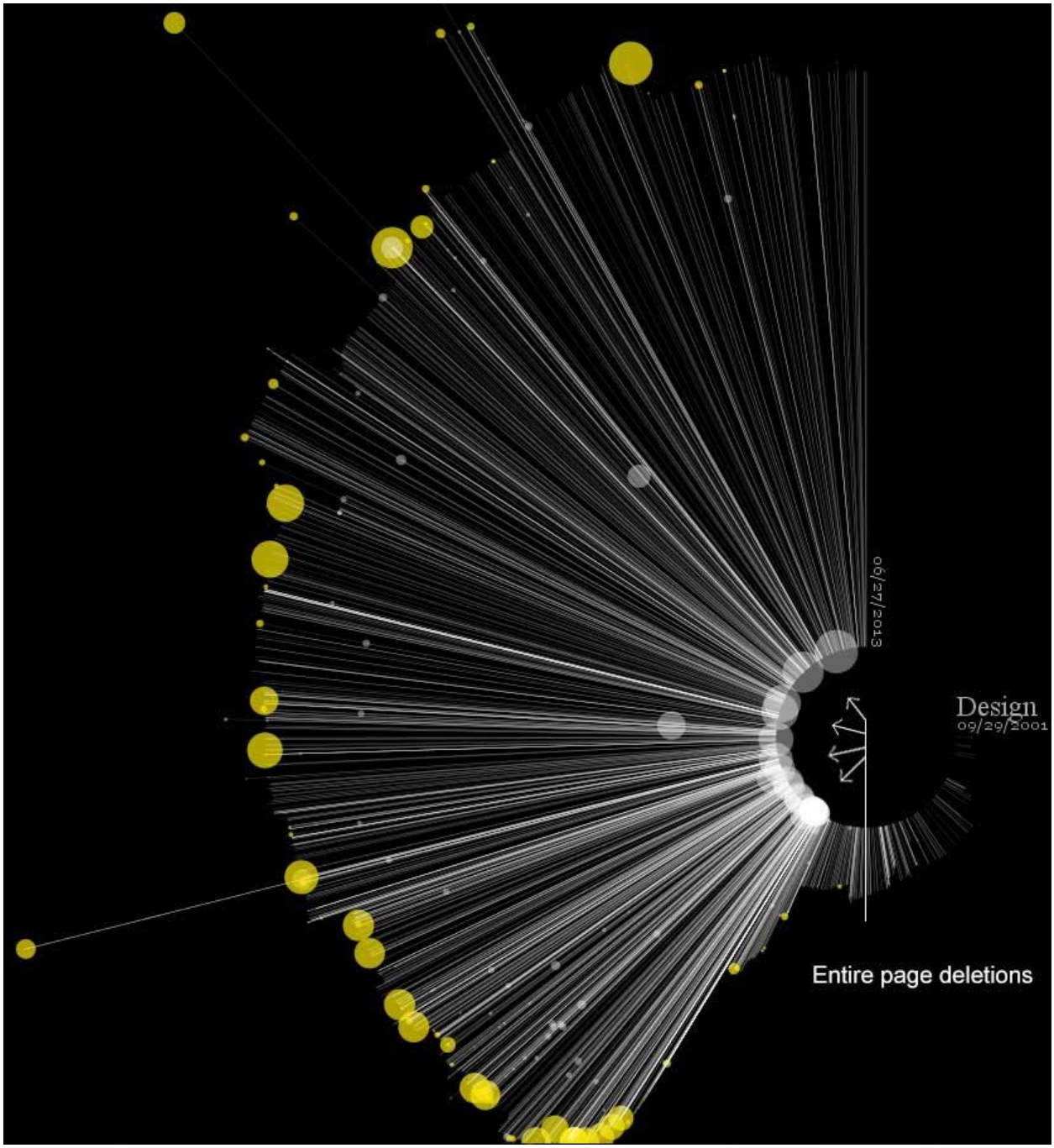


Figure 14: Organic Turbulence

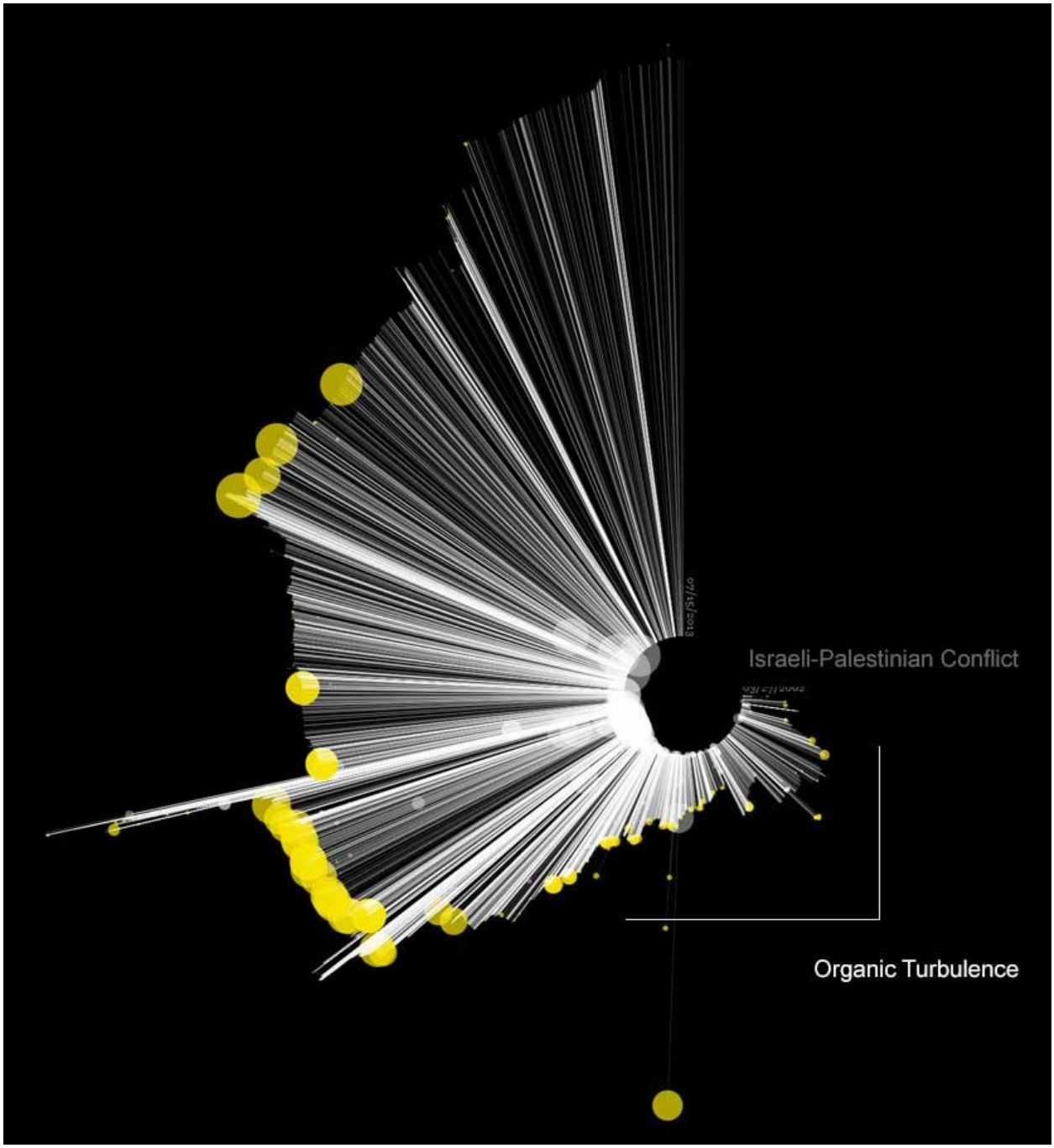


Figure 15: Rigid Growth

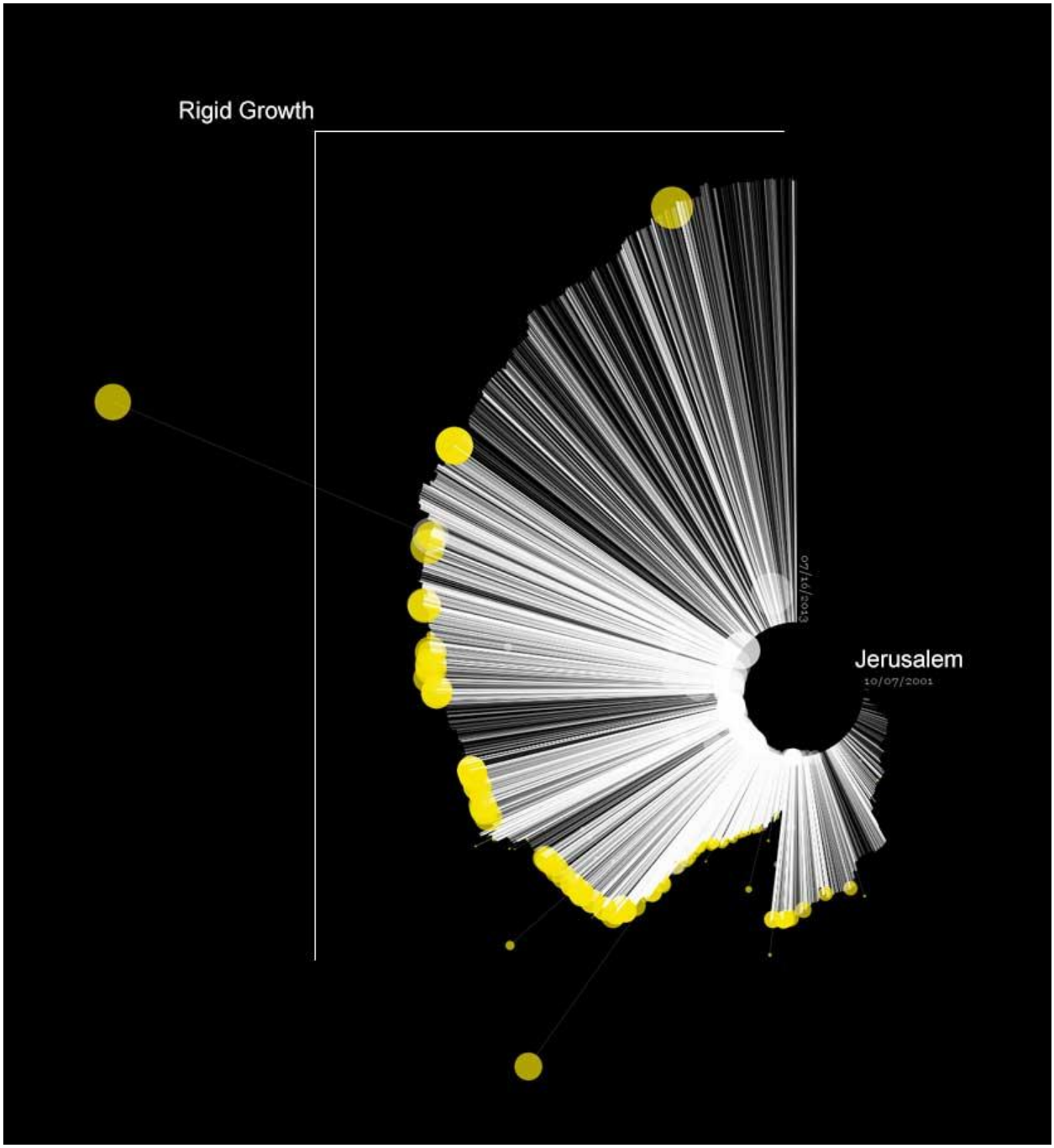


Figure 16: Map Correlation

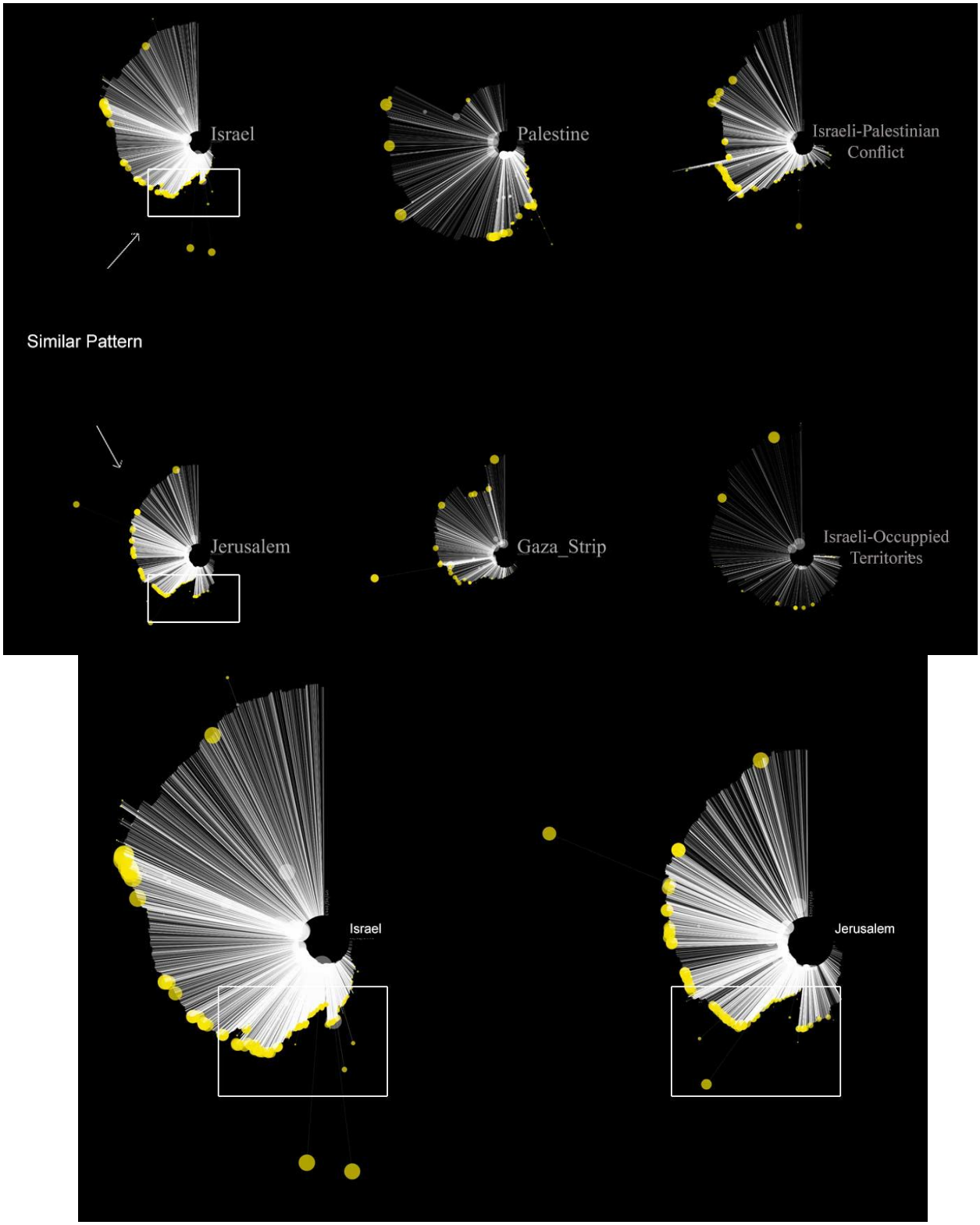
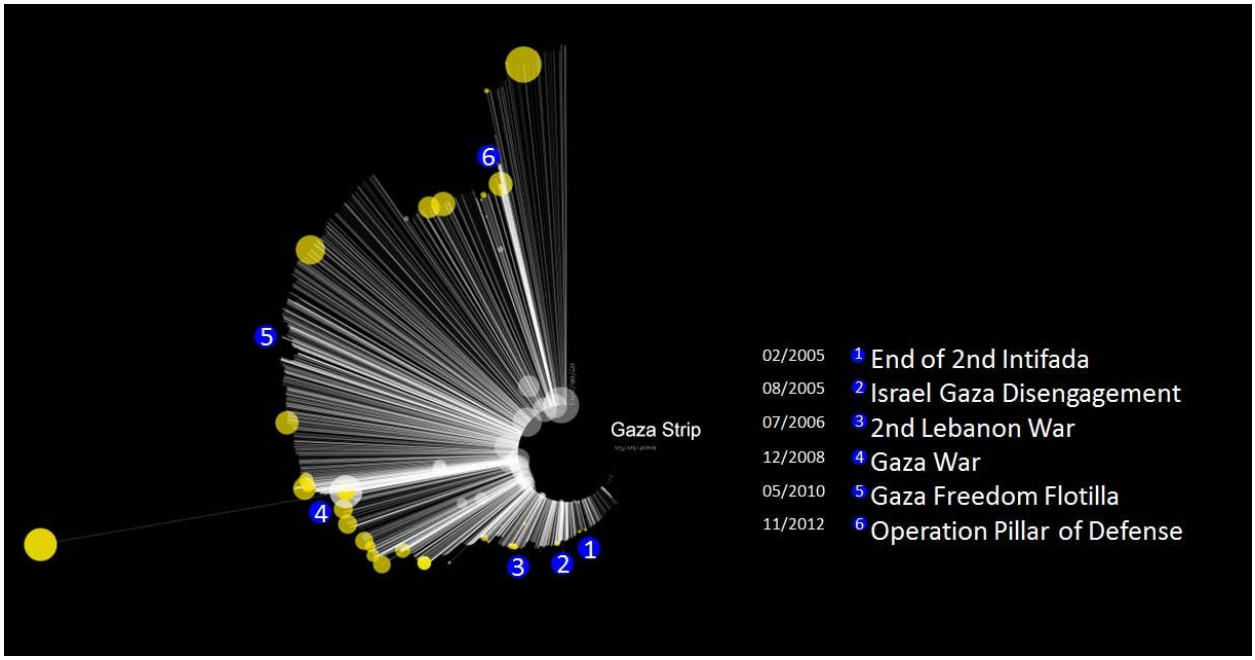


Figure 17: Current Event Comparison



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