A Song and Dance Number ?

Stephen G. Kobourov
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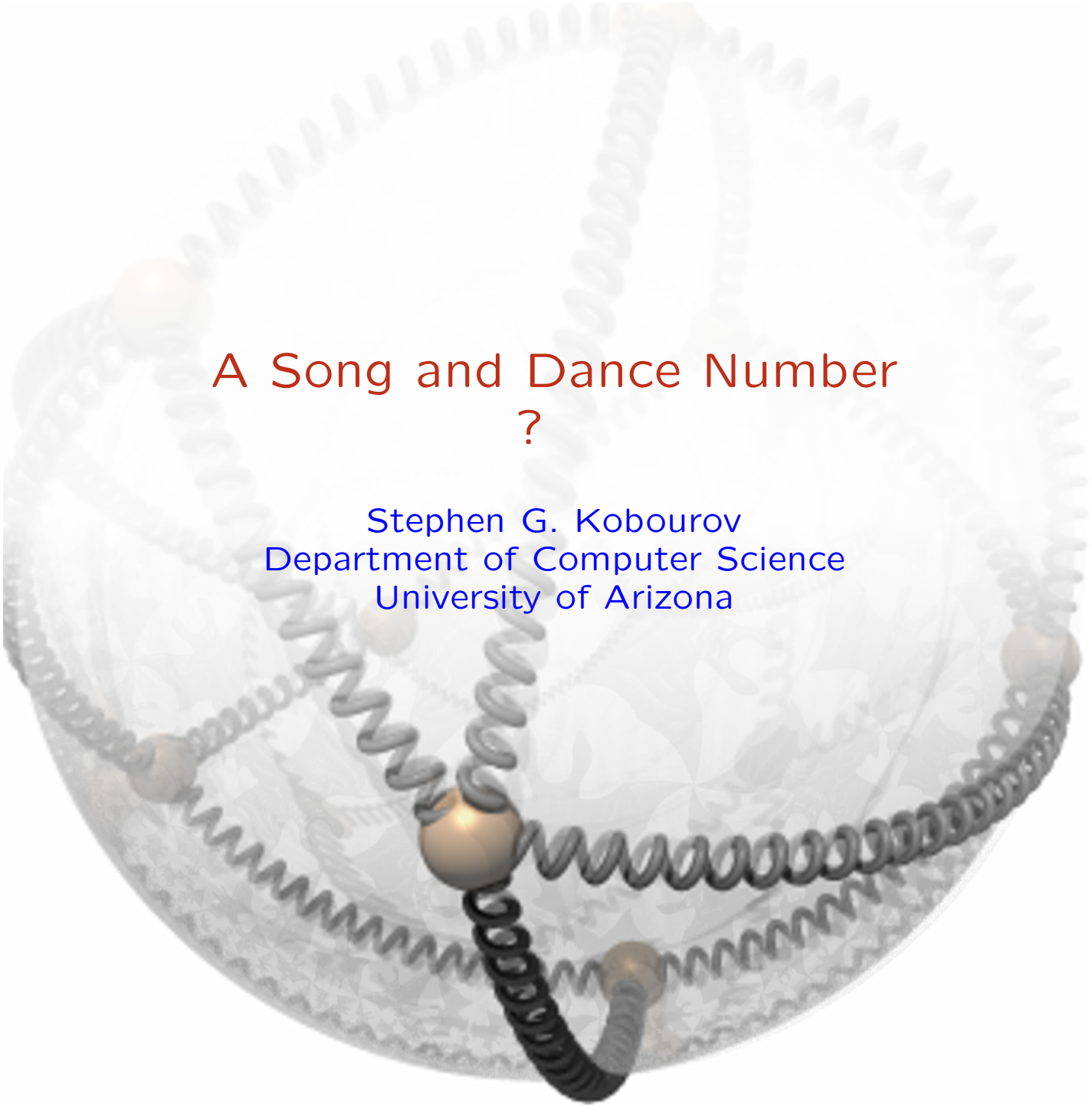
University of Arizona



A Song and Dance Number
(or Audio and Video for Program Comprehension)

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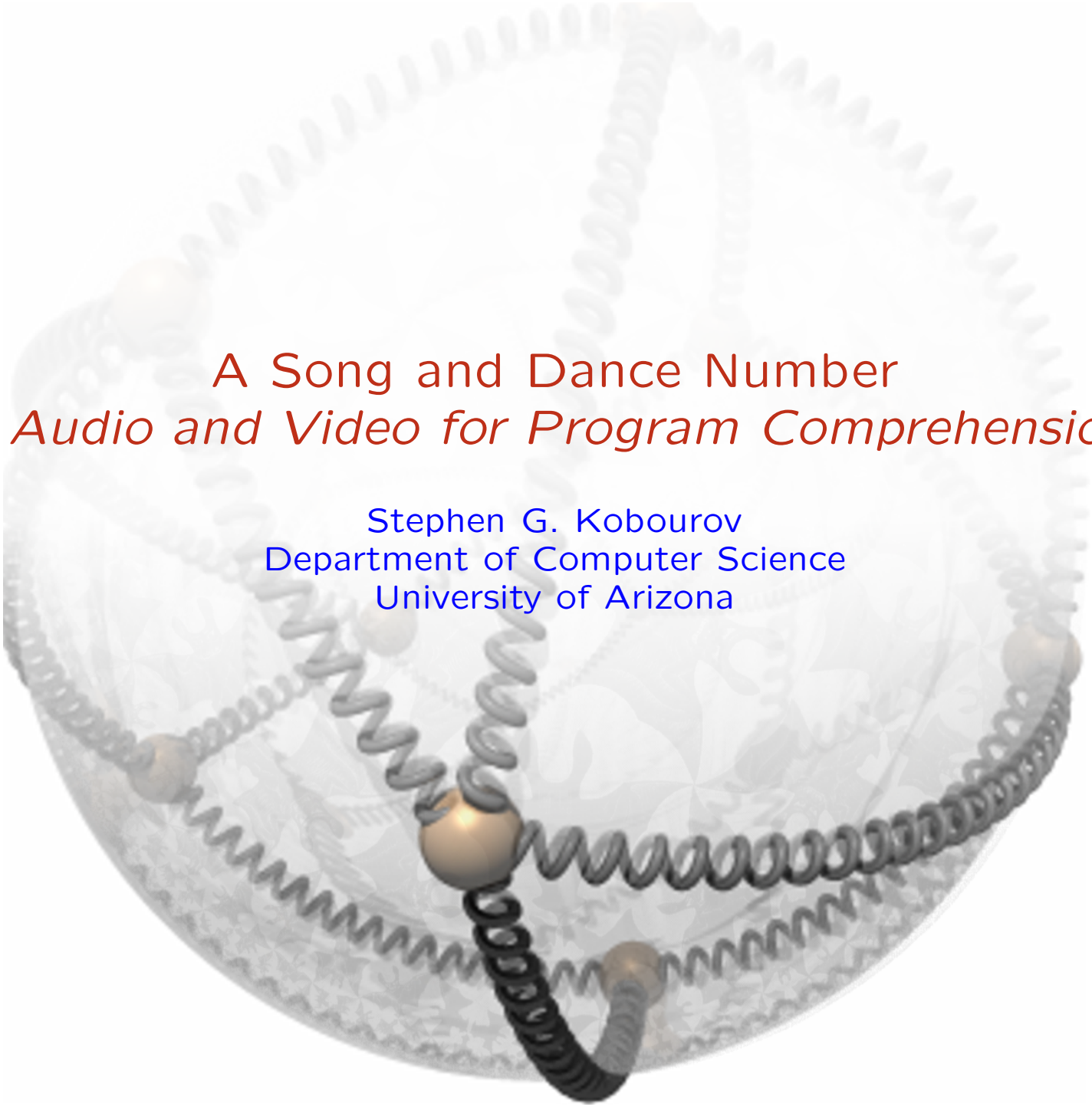
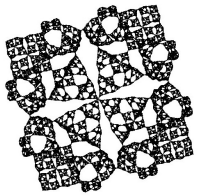
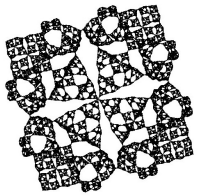




Program Comprehension

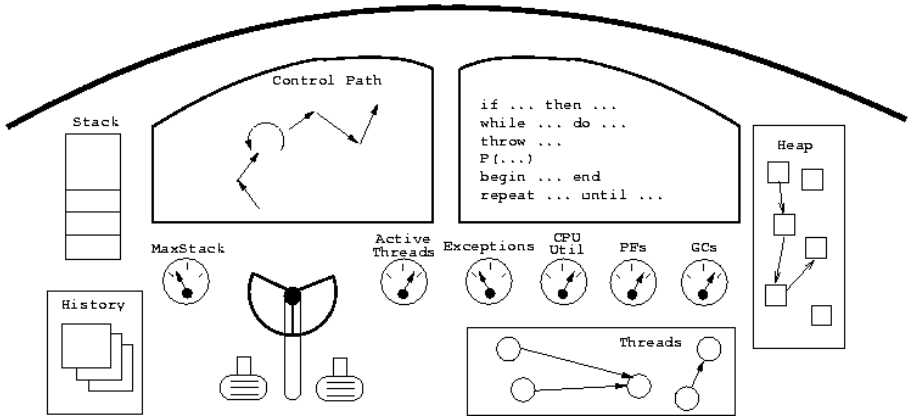
- Real-world programs
  - large, complex, evolving...
  - built by many programmers
  - maintained by other programmers
  - programmers of varying skill levels

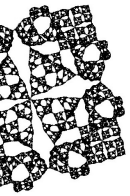
- Program comprehension
  - gather static, dynamic, historical data
  - present data in simple, coherent way
  - development, debugging, maintenance, tuning



Total Program Awareness

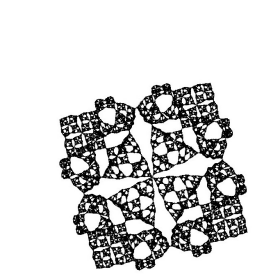
- Visualize and auralize everything: *Programmer's Cockpit*
  - garbage collection activity, exception activity
  - number of page faults, active threads
  - maximum stack depth, execution stack behavior
  - heap graph, thread wait-graphs, call graphs, pdg's
  - control flow graphs, inheritance graphs, package graphs
  - version history, CPU utilization



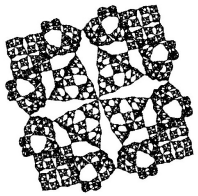


Total Program Awareness

Visualization

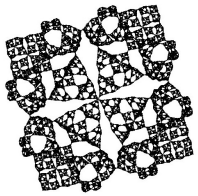


Visualization



Visualization

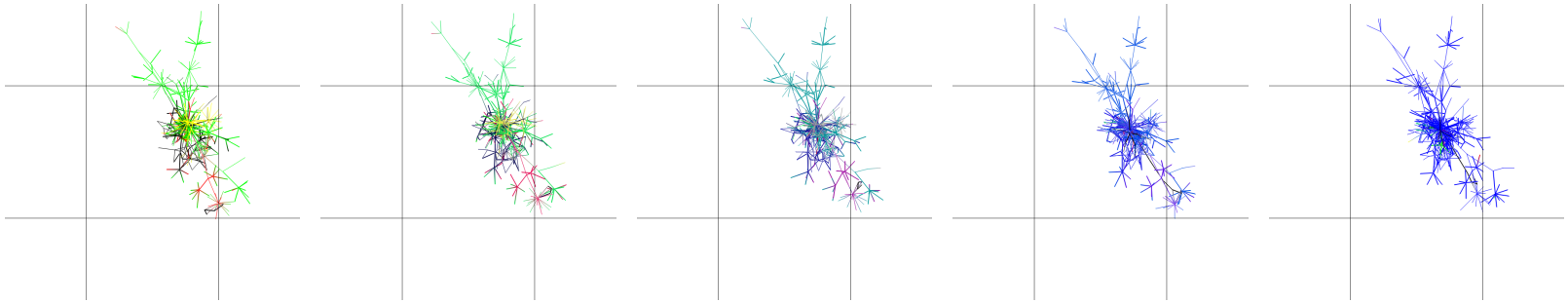
- Why visualize?
  - when we do not know what we are looking for
  - to leverage the visual processing machinery of the brain

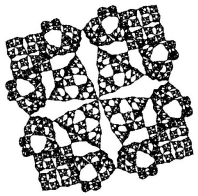


Visualization

- Graphs, graphs, and more graphs
  - static graphs
  - evolving graphs
  - dynamic graphs

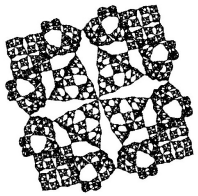
- Evolution of software
  - why is the program structured that way?
  - who worked on which part and when?
  - which parts of the code are unstable?



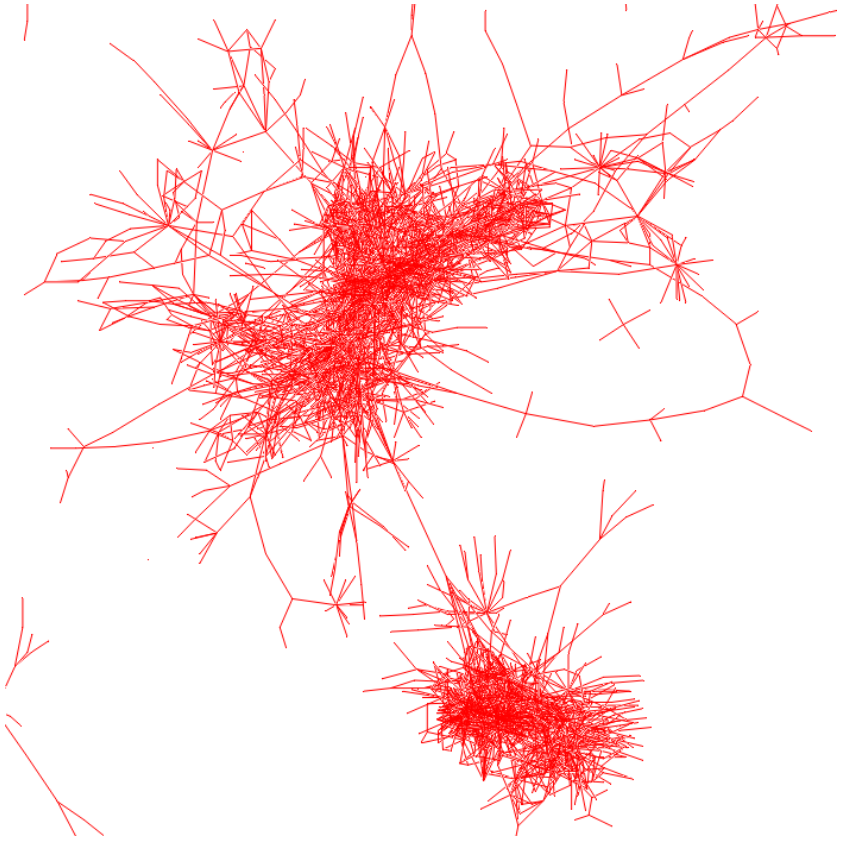


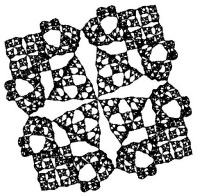
SandMark

- The SandMark system (Christian Collberg)
  - software watermarking
  - tamper-proofing
  - code obfuscation
- SandMark history
  - 26 developers
  - 3+ years of CVS data
  - 100,000+ lines of Java code



SandMark Call Graph





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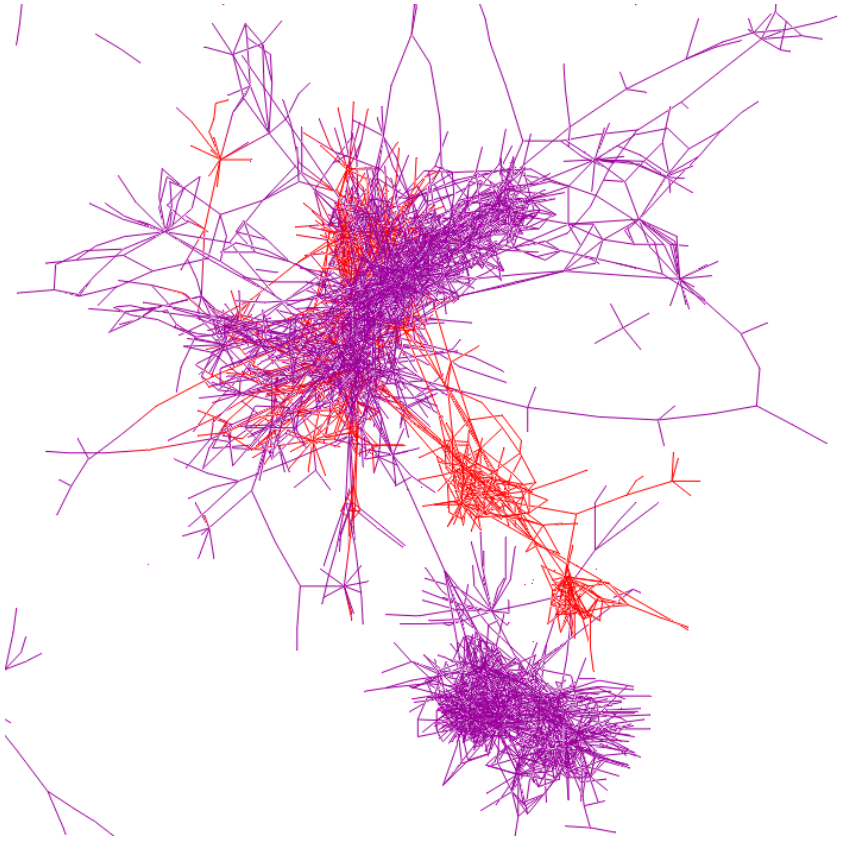

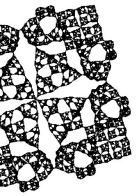

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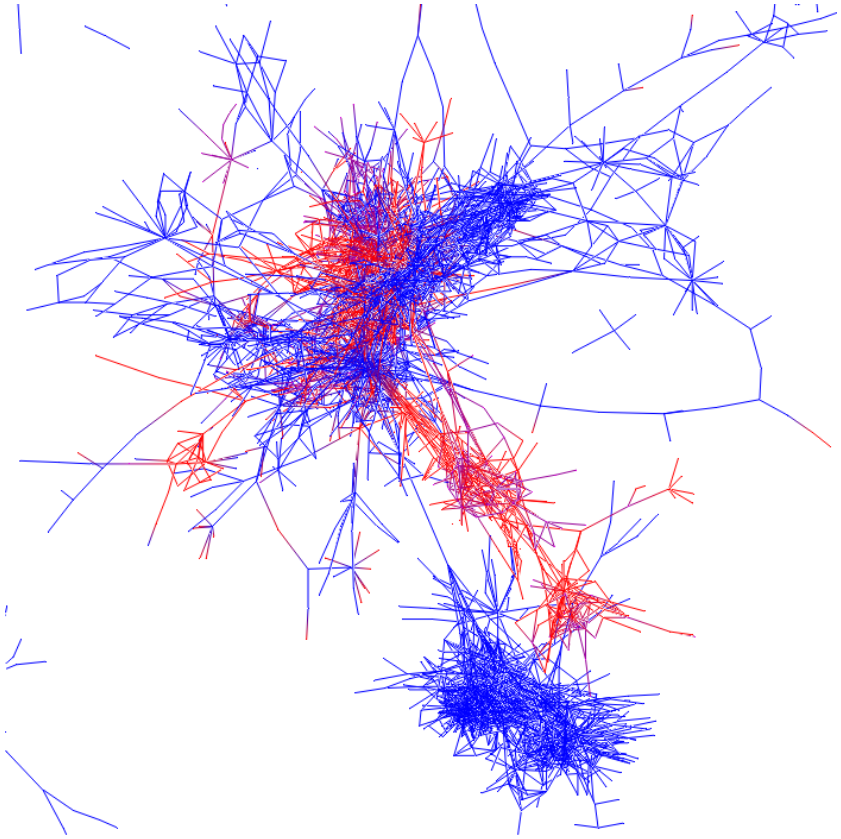

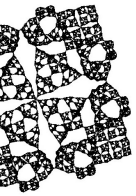

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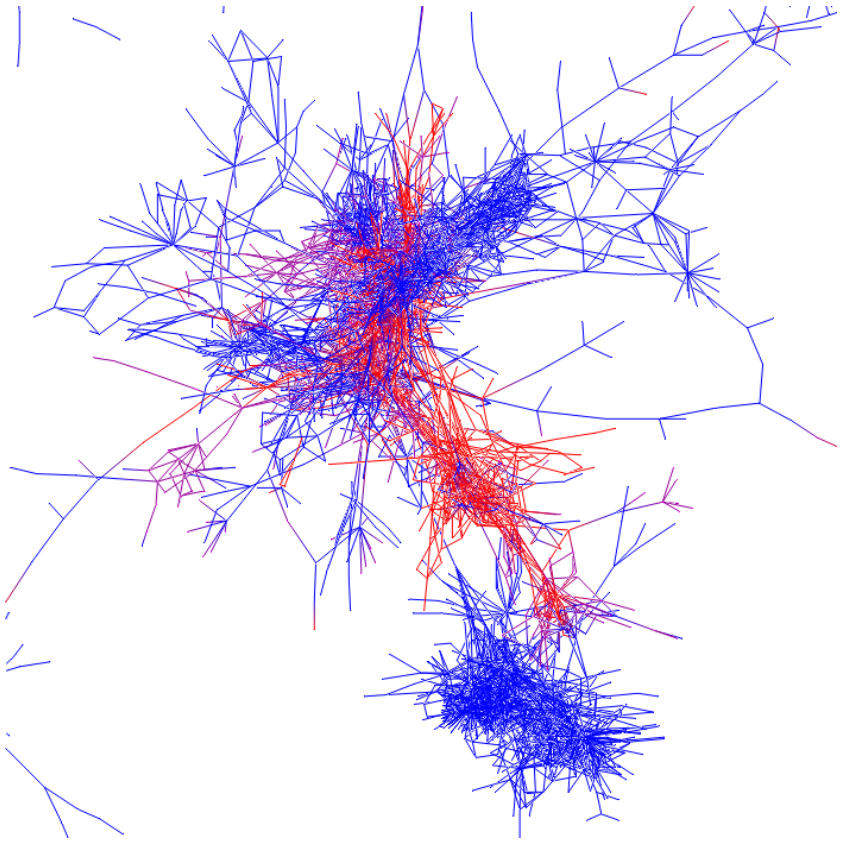

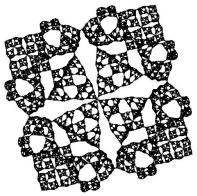

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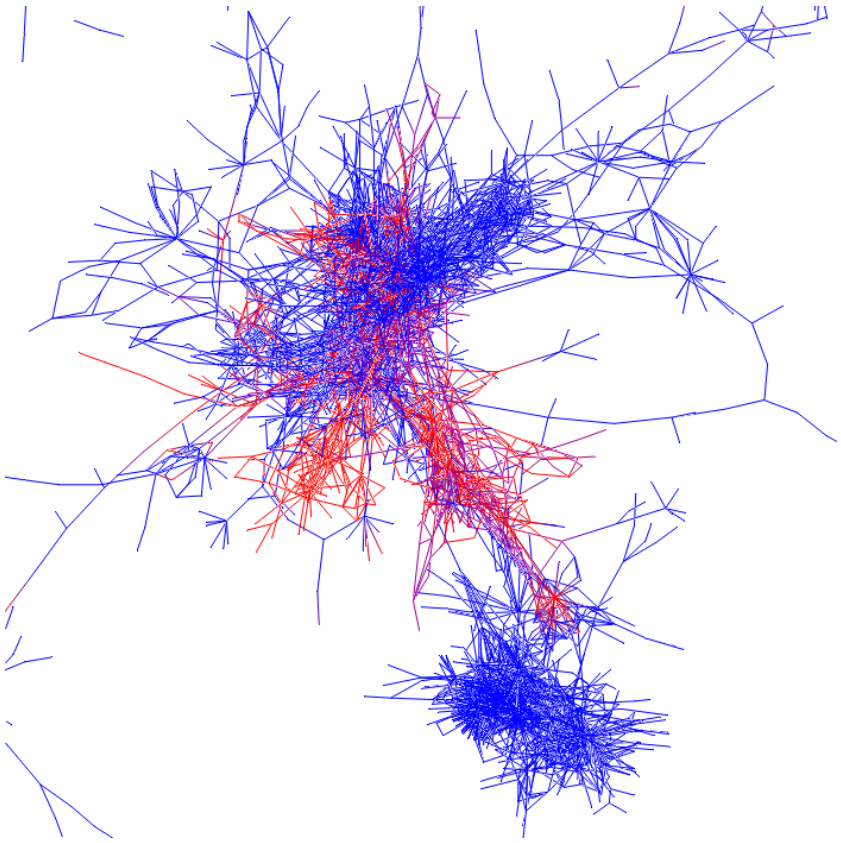

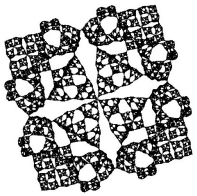

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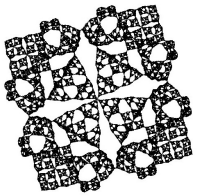
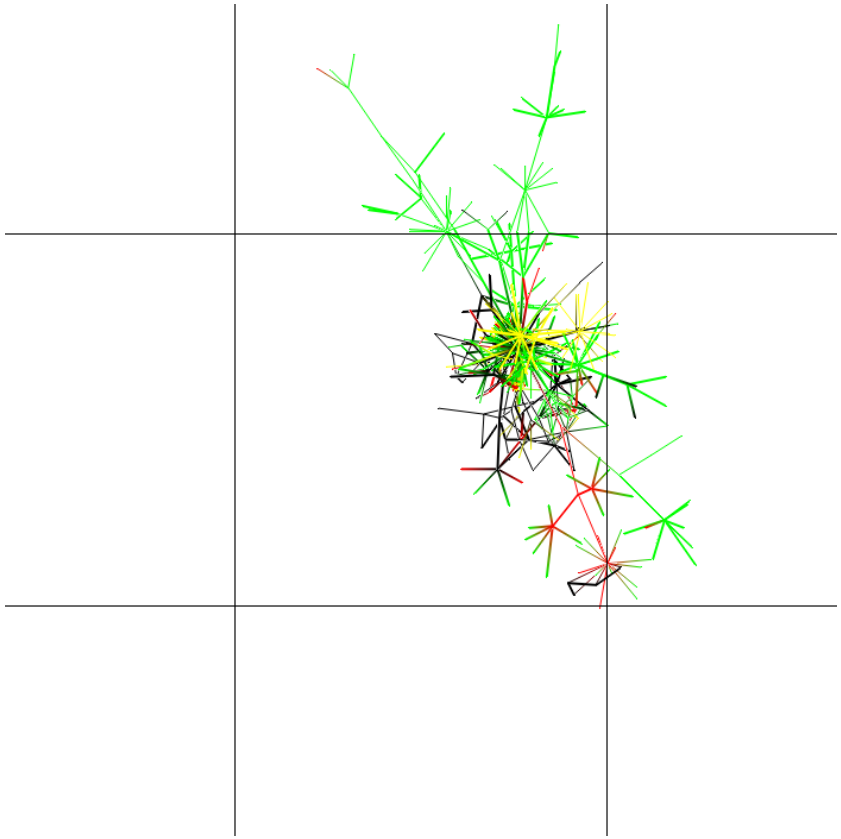
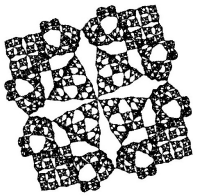


SandMark Inheritance Graph





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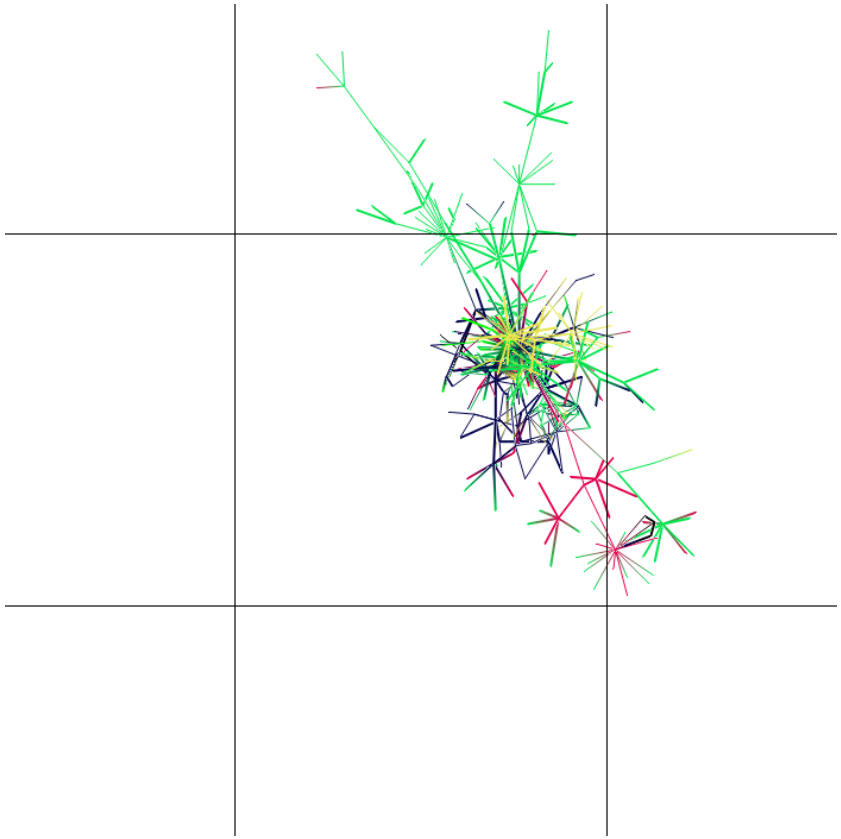

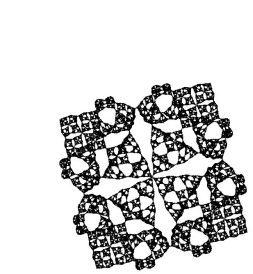

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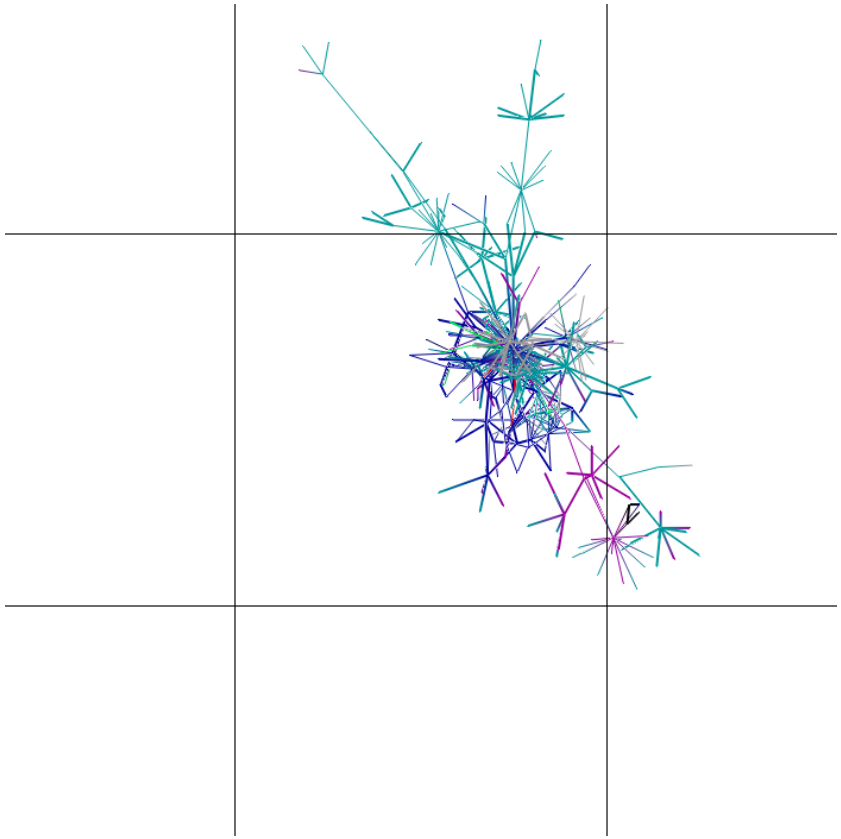

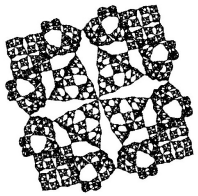

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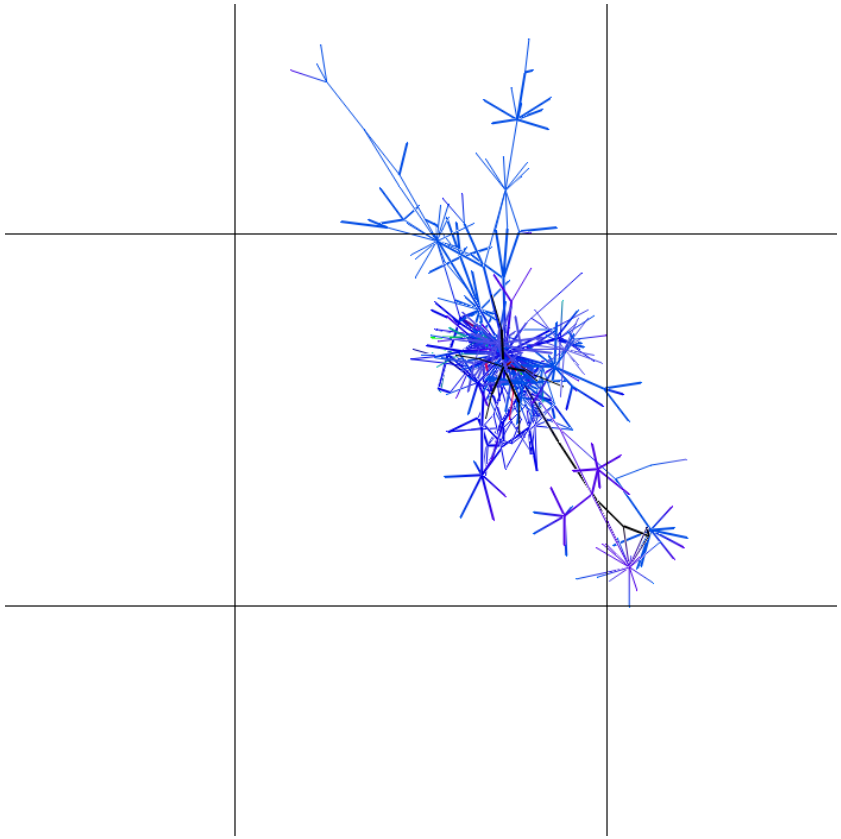

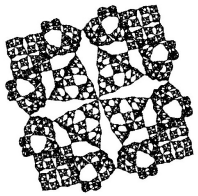

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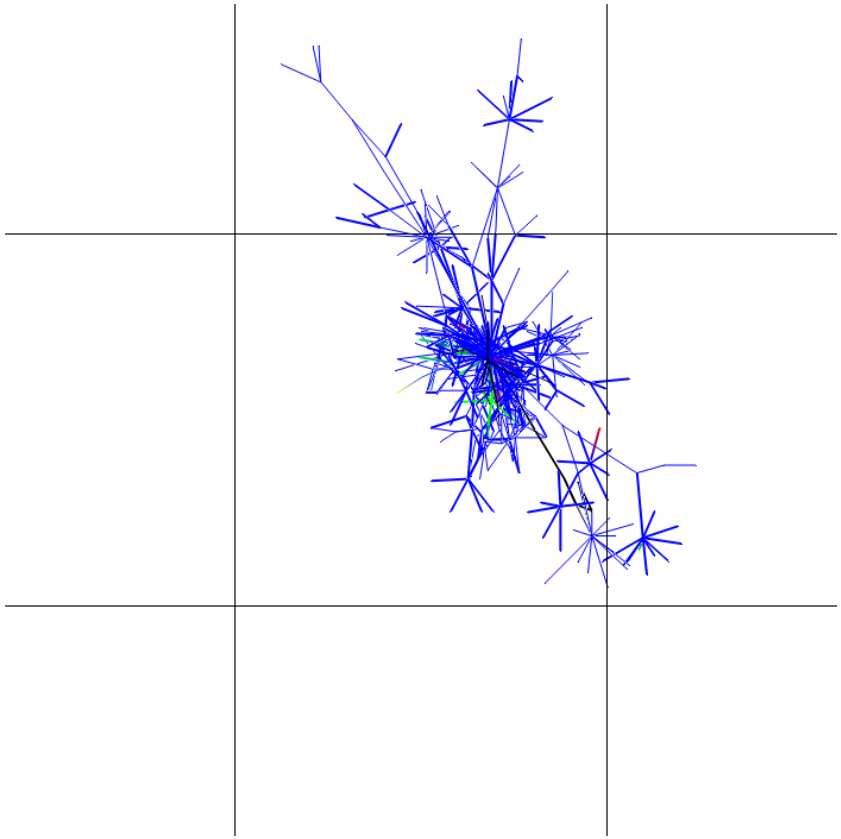

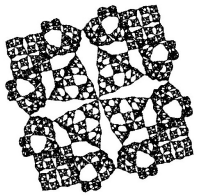

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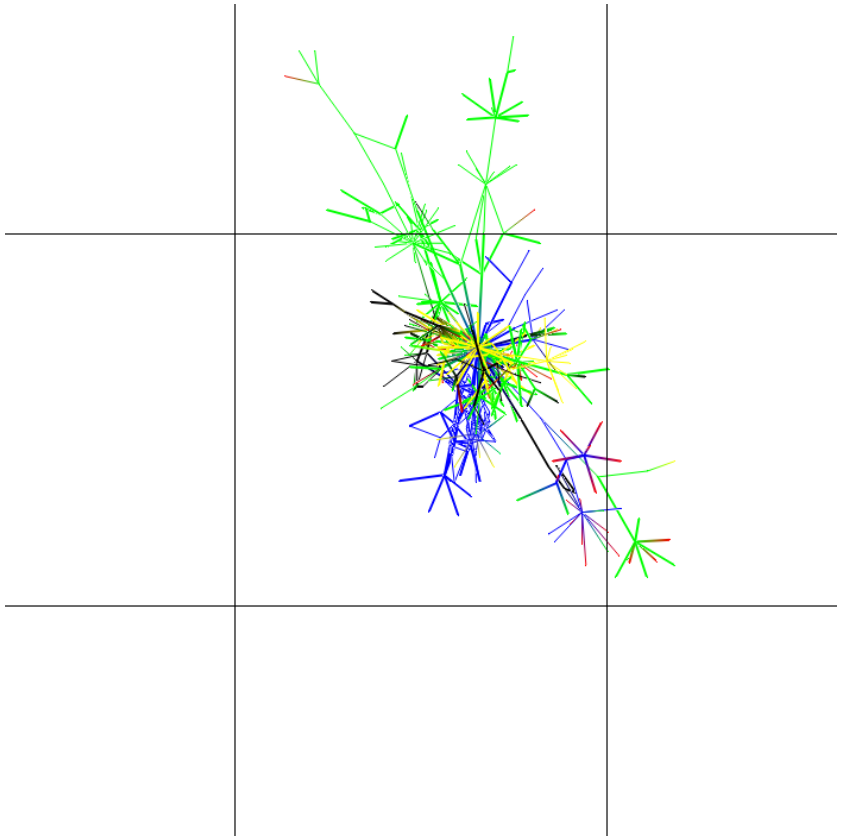

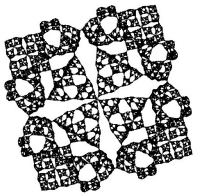

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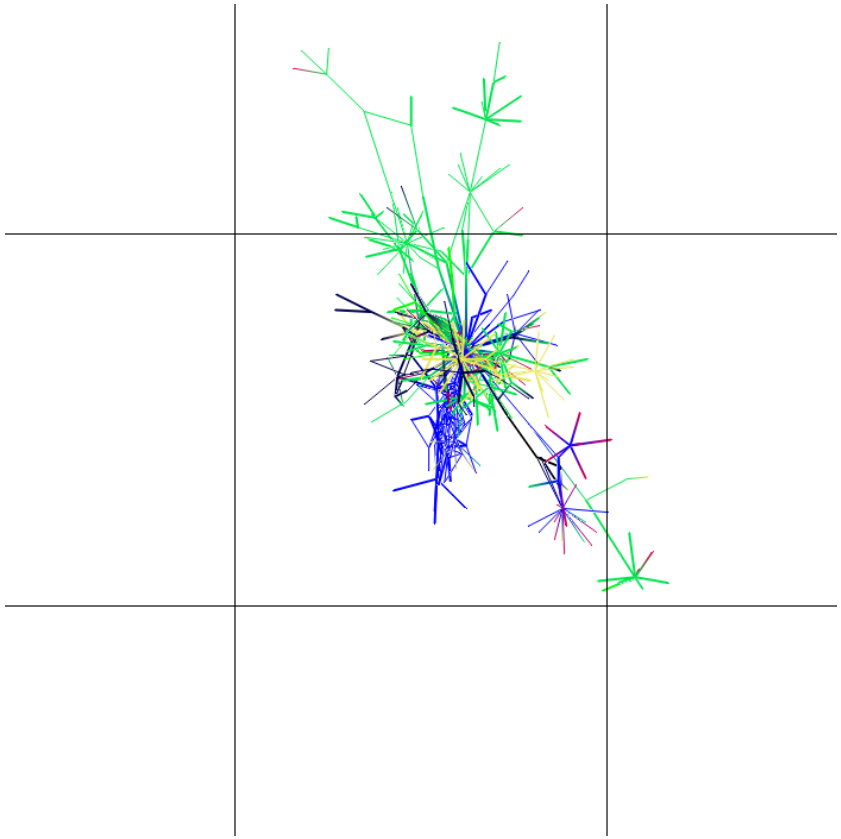

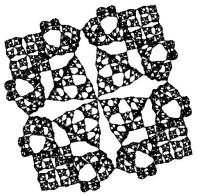

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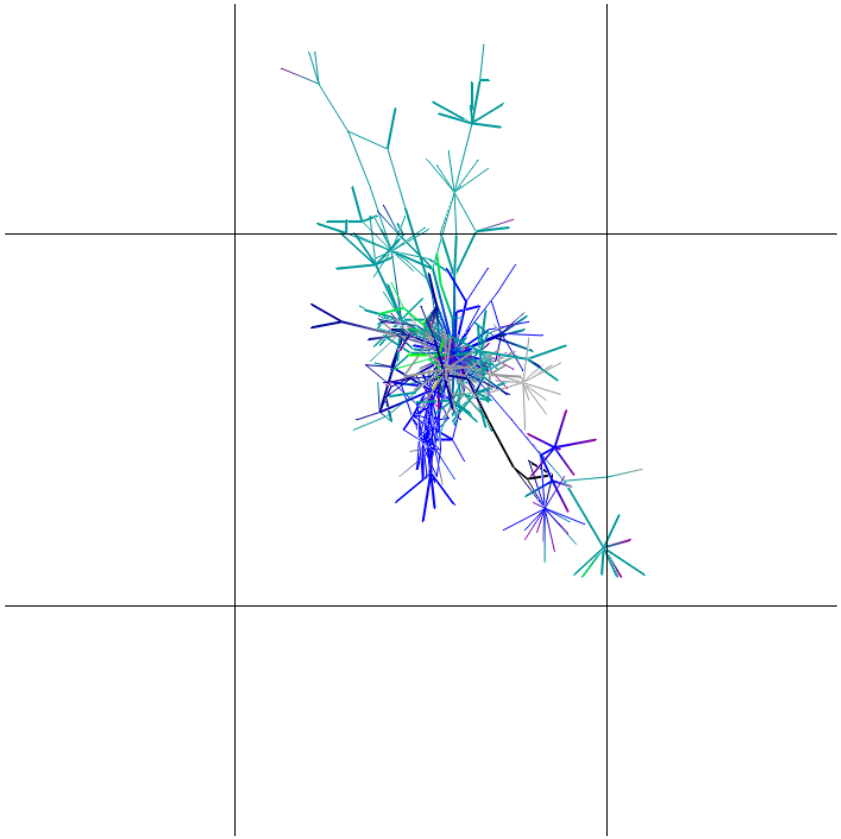

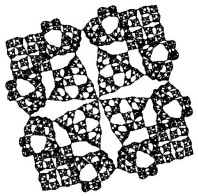

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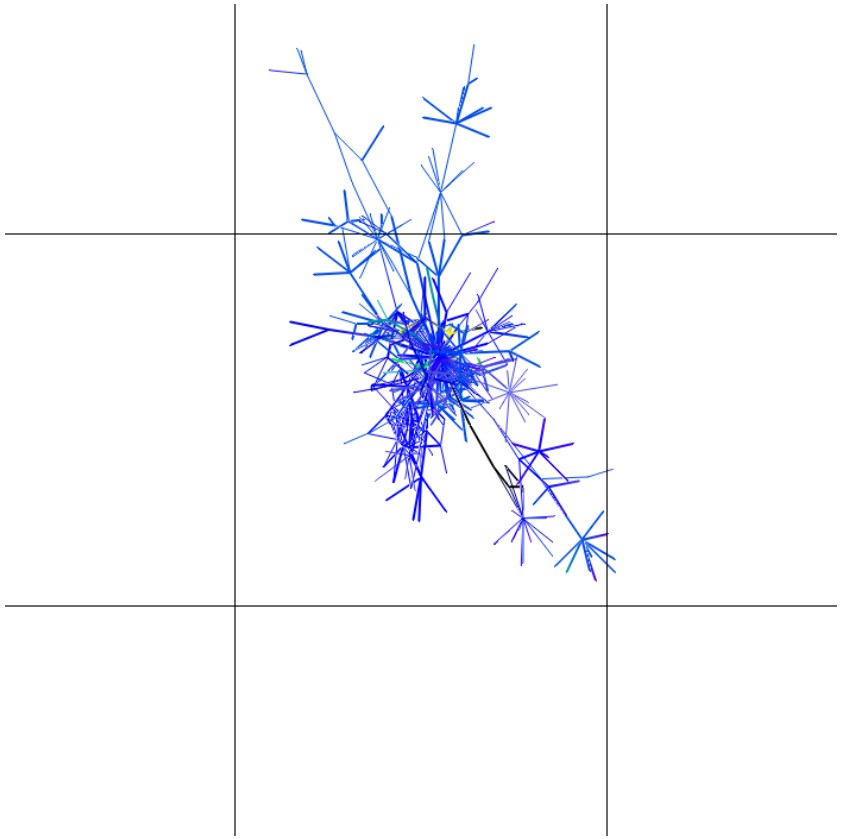
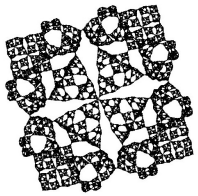
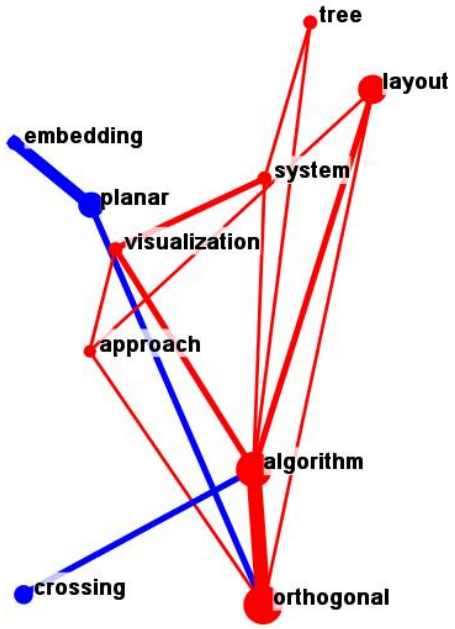
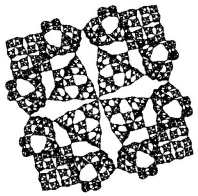




Graph Visualization

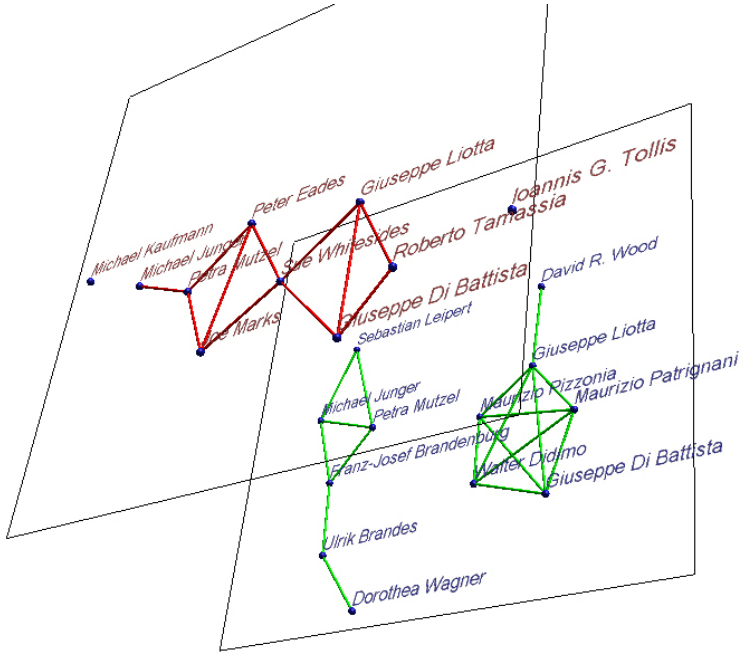
- In theory
  - static unlabeled graph
  - vertices (objects)
  - edges (relationships)
  - goal is *nice* drawing
- In practice
  - dynamic or evolving
  - weights on vertices and edges
  - uncertainty
  - meaningful placement
  - spatial locality
  - temporal locality

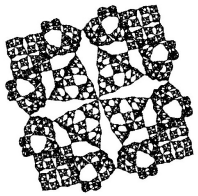




Visualization Wish-list

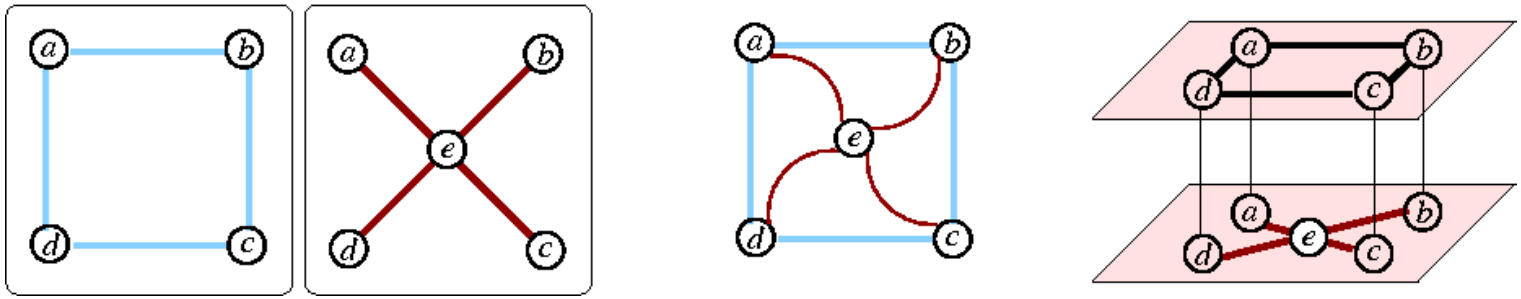
- Each drawing should be readable
  - individually "nice" layouts
  - no crossings, symmetries, etc.
- Mental map preservation
  - structures, relative locations
  - animation, morphing
- In theory ... but in practice...
  - conflicting goals
  - domain knowledge
  - issues of scale

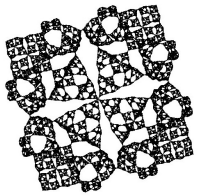




Visualizing Evolving Graphs

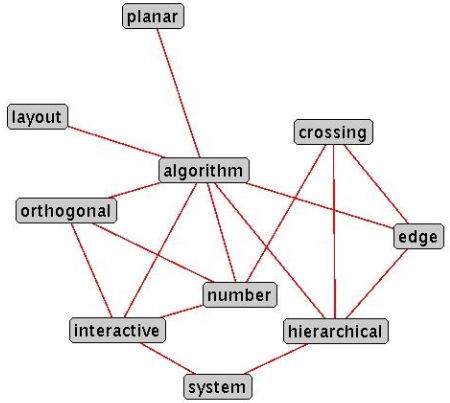
- Time model
  - a *timeslice* for each unit of time
  - a snapshot of the graph
- Viewing the evolving graph
  - different views
  - morphing between timeslices
- Beautiful theoretical problems

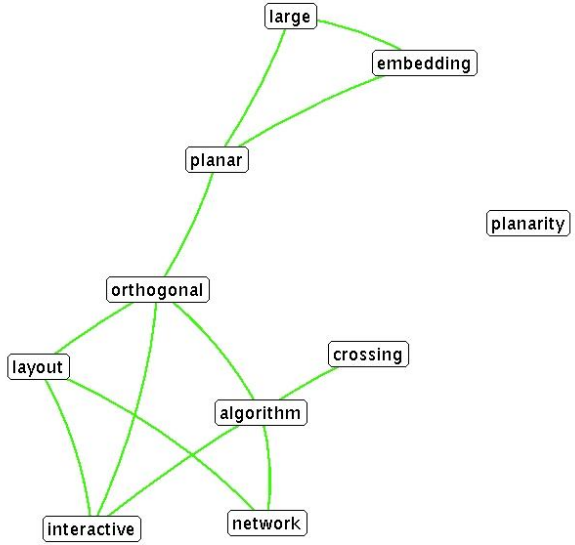


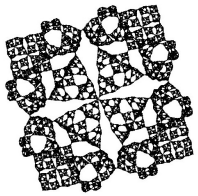


Readability and Mental Map

- Individual layouts for each graph
  - maximizes individual readability
  - no mental map preservation

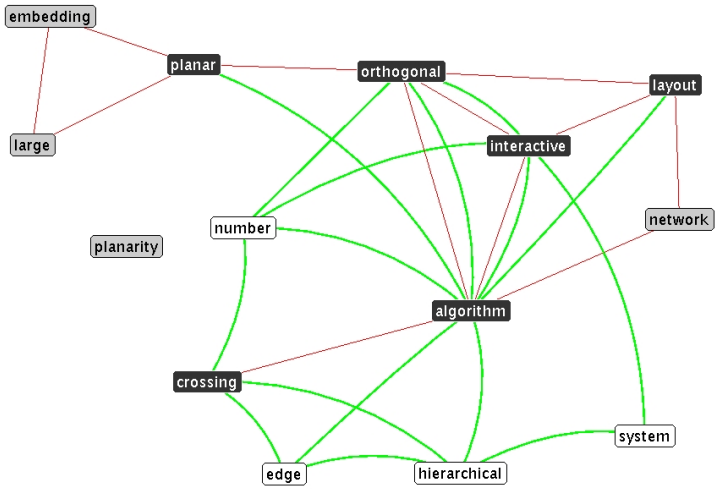


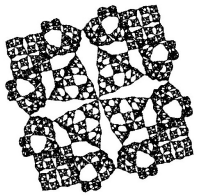




Readability and Mental Map

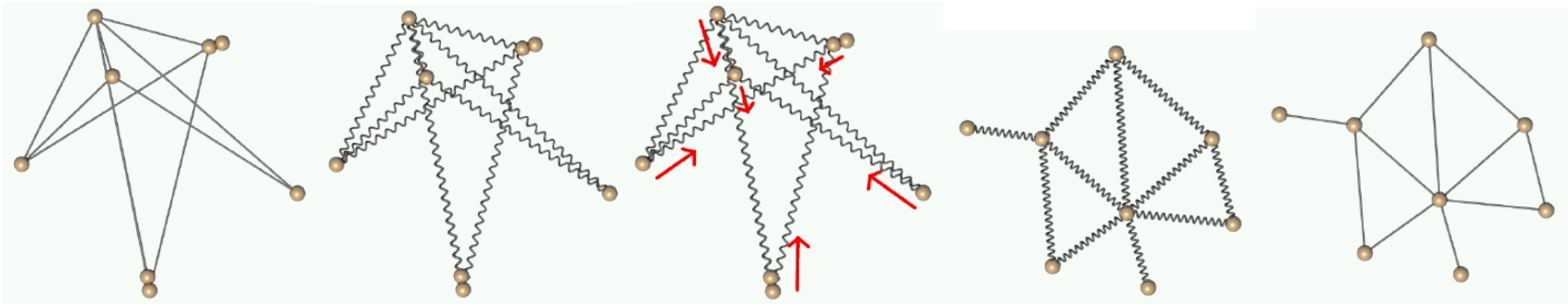
- Individual layouts for each graph
  - maximizes individual readability
  - no mental map preservation
- Simultaneous embedding
  - no individual readability
  - maximizes mental map preservation

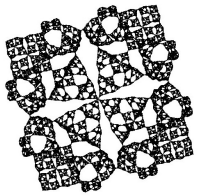




Force-Directed Methods

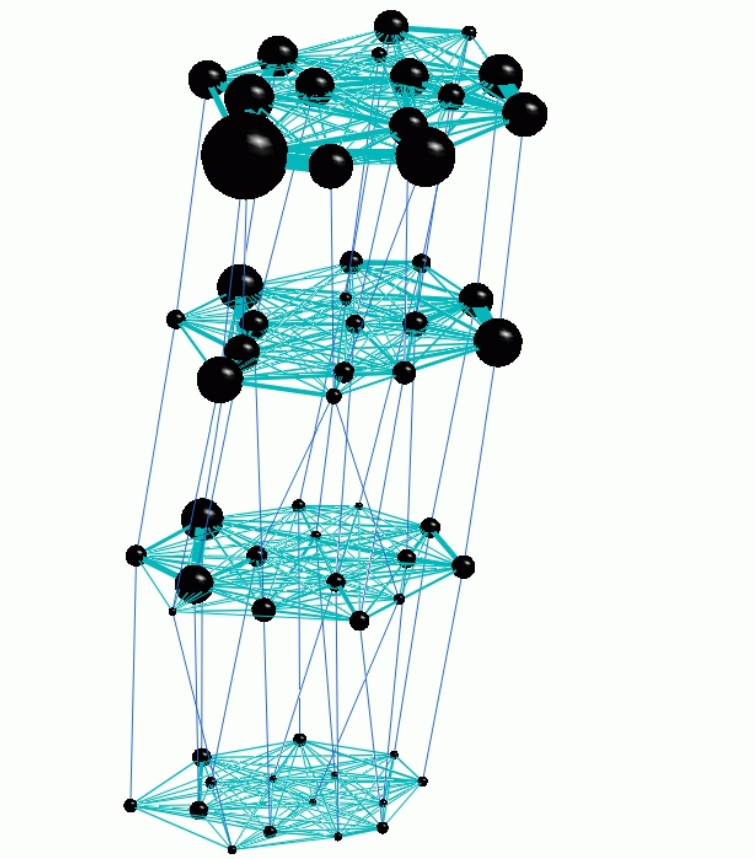
- Assign energy function to the current layout
  - based on graph distances [KK]
  - based on attractive/repulsive forces [FR]
- Energy model
  - characterizes stability
  - iterative improvement
  - minimal energy $\Rightarrow$ good layout





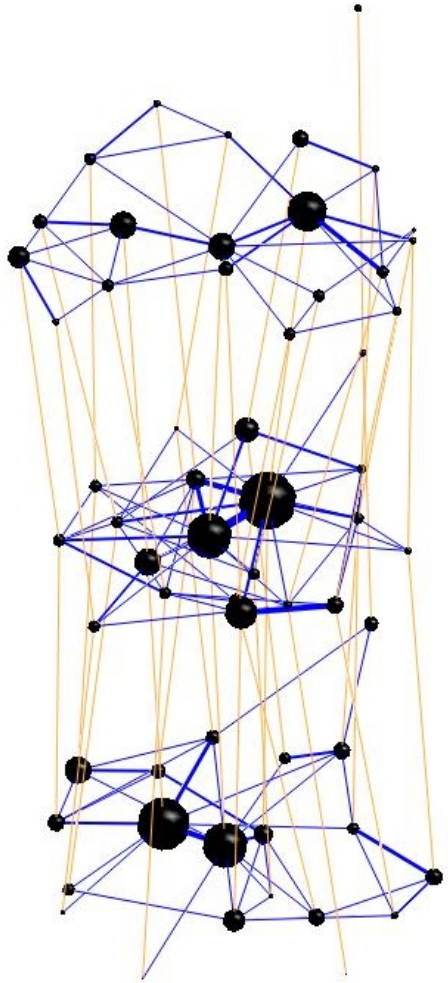
Making It Work

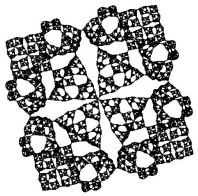
- Force-directed methods
  - modification of Kamada-Kawai
  - modification of Fruchterman-Reingold
- Large graphs become even larger
  - multi-scale methods
  - non-random initial placement
  - high-dimensional embedding
- Readability and mental map
  - enforced via inter-timeslice edges
  - using vertex-weights and edge-weights



Merged Graph

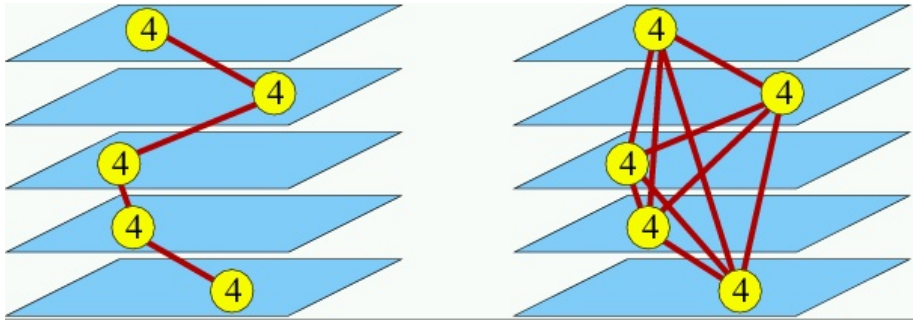
- $G_1, G_2, \ldots, G_k \Rightarrow$ merged graph $\mathcal{G} = (V, E)$
  - $V = V_1 \cup V_2 \cup \ldots \cup V_k$
  - $E = E_1 \cup E_2 \cup \ldots \cup E_k \cup E^*$
  - E^* contains the inter-timeslice edges
- Weights: $w(v)$ and $w(e)$
  - sum of weights in each timeslice
  - or cumulative (collaboration graph)
  - $w(e) = \beta(w(u) + w(v)), e = (u, v) \in E^*$
  - $0 \leq \beta < \infty$: *balance control*



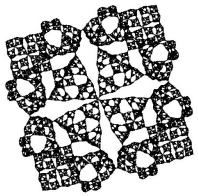


Modified Layout Algorithm

- Inter-timeslice options
  - weight of inter-timeslice edges in E^*
  - connectivity of inter-timeslice edges

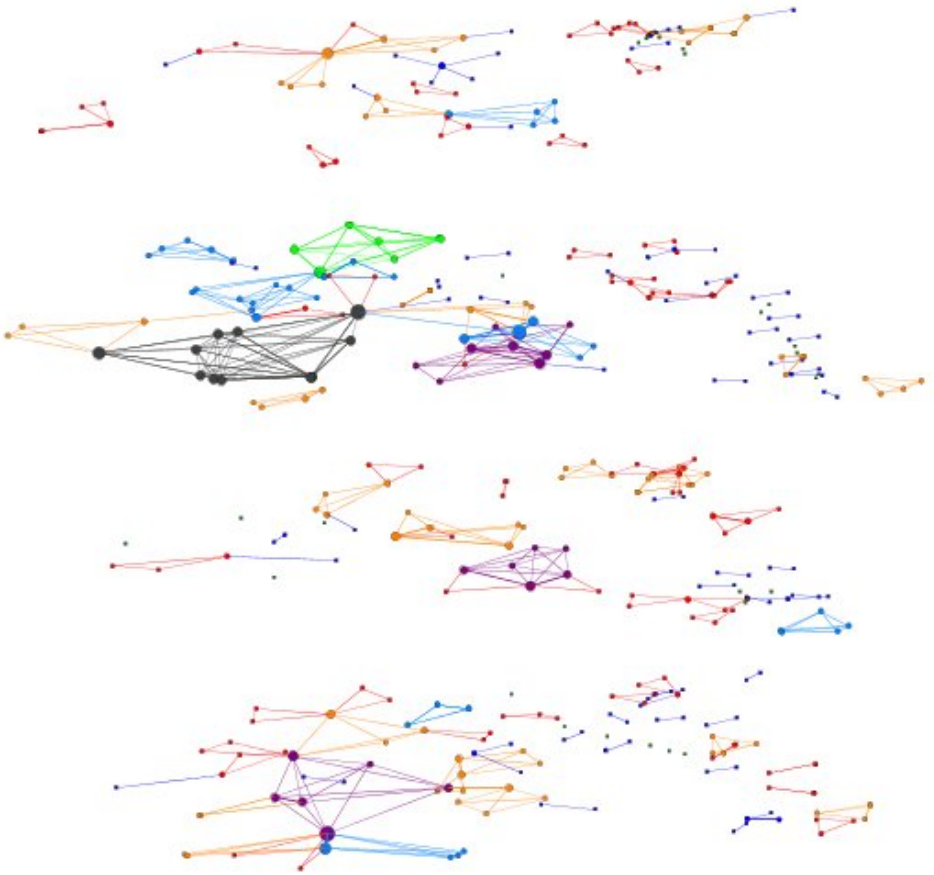


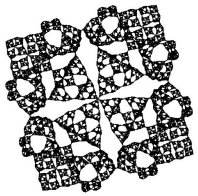
- Role of inter-timeslice edges
  - $w(e) = \beta(w(u) + w(v)), e = (u, v) \in E^*$
  - $\beta \rightarrow 0 \Rightarrow$ good individual layouts
  - $\beta \rightarrow \infty \Rightarrow$ good mental map preservation
- Need to deal with weighted graphs



Modified Layout Algorithm

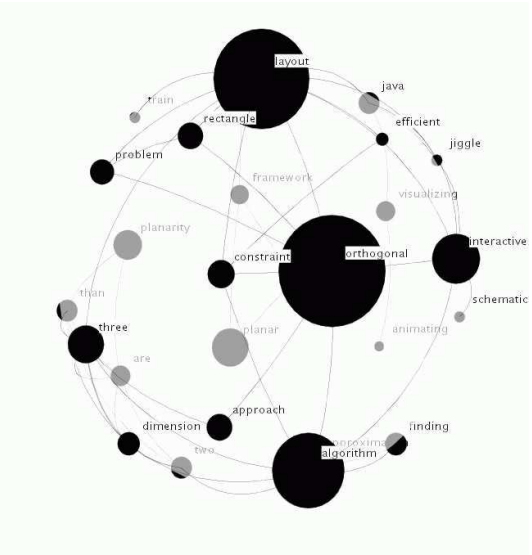
- Heavy vertices: persistent
  - further apart
  - closer to center
  - move little
- Light vertices: transient
  - (dis)appear on the periphery
  - move more
- Heavy edges: persistent
  - shorter in length
- Light edges: transient
  - less important

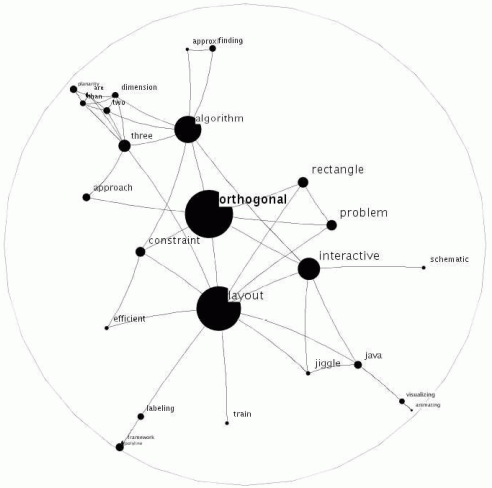


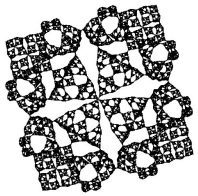


The graphael System

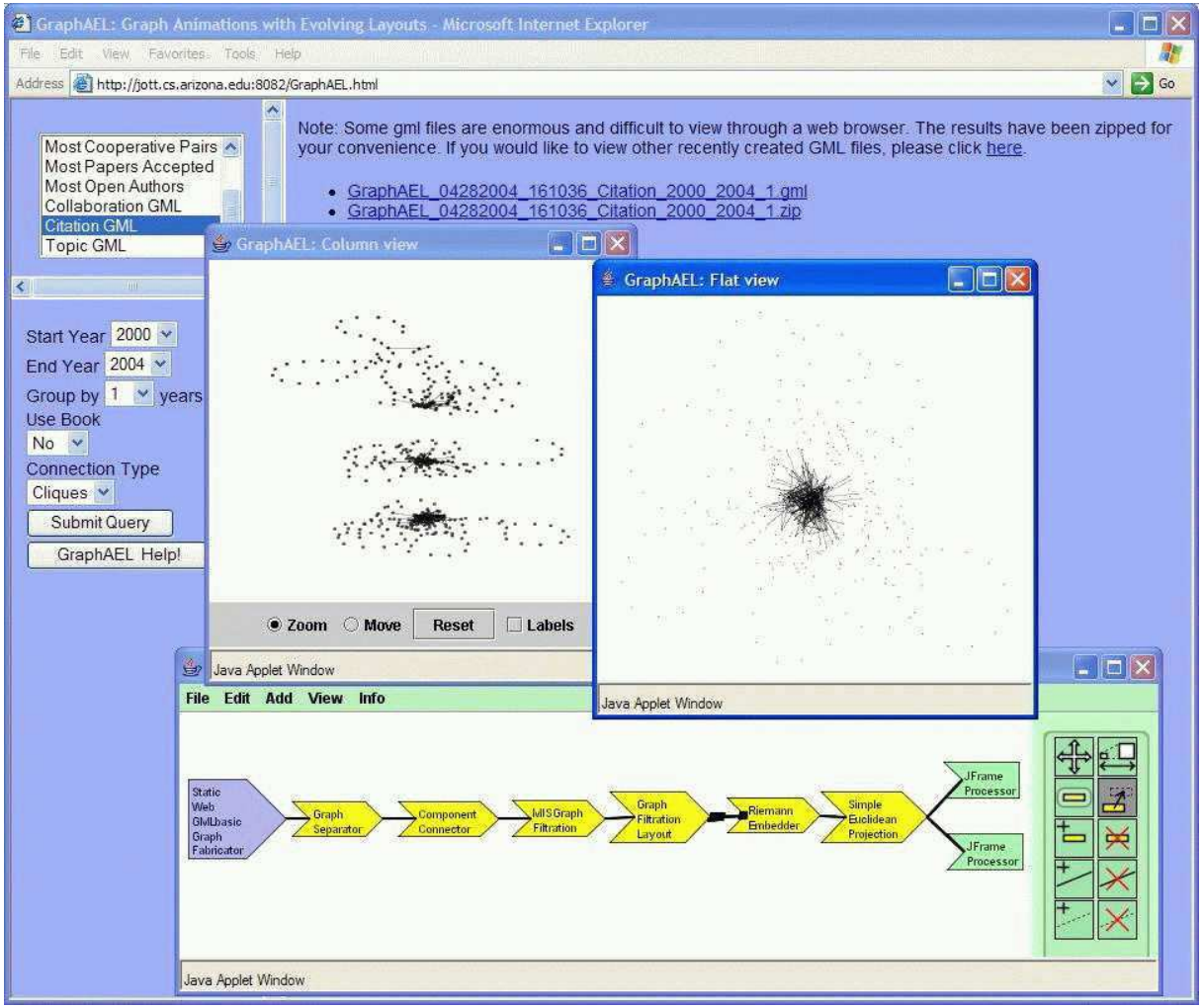
- Yet another graph drawing system
- Features
  - static, evolving graphs, morphing
  - hyperbolic, spherical embedding
  - as a database plugin: ACM, InfoVis, GD
  - user-control over CFG
- Availability
  - `http://graphael.cs.arizona.edu`
  - demo

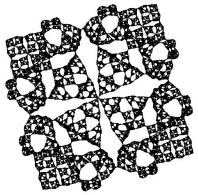






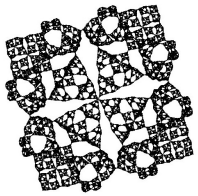
The graphael System





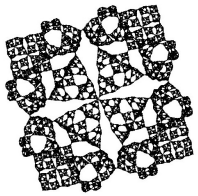
Auralization

- Sonification examples
  - Geiger counter
  - stick-shift cars
  - spinning hard disks
- Human hearing
  - sensitive to (a)periodic sounds
  - detects small changes in frequency
- Suitable for program analysis?
  - rapidly changing data can be missed visually
  - good sound cues: repeated patterns
  - augment visual cues: doesn't require user focus
- How does a good program sound?



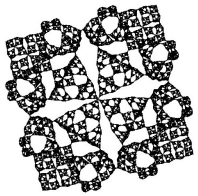
JMusic

- Auralization for Java programs:
  - anotation script
  - auralization script
  - jar file
- Anotation
  - number of method calls
  - number of array manipulations
  - track loops
- Auralization
  - change tempo, key, pitch, instrument
  - change melody, flip major/minor key



Future Work

- Visual
  - which graphs? (inheritance, pdg's,...)
  - where? (locality)
  - what? (changes)
- Audio
  - when? (development, debugging, tuning,...)
  - how? (mapping between events and sounds)
- Cockpit
  - computer game metaphor
  - charts, dials, controls



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  - Armand Navabi (BS)
  - David Forrester (BS)