Data Aggregation and Alternative Visualization Techniques for Parallel and Distributed Program Analysis

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TUD-ZIH-Colloquium – Dresden, Germany

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Introduction

- Performance analysis $\rightarrow$ visualization
  - Register behavior during program execution
  - Offline, or post-mortem, visual analysis
- Traces characteristics
  - Timestamped and typed events
  - Very detailed in time $\rightarrow$ micro to nanoseconds
  - Many observed entities (processes, threads)

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Analysis through trace visualization

- Explore human perception, intuitive
- Interactive and exploratory approach

Challenges and Motivation

- Very large applications
  $\rightarrow$ Top500 has machines with 1.5 million cores
- Low-intrusion tracing techniques
  $\rightarrow$ Buffering, hardware support, simulation traces

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- Data representation without care
  $\rightarrow$ may deceive understanding

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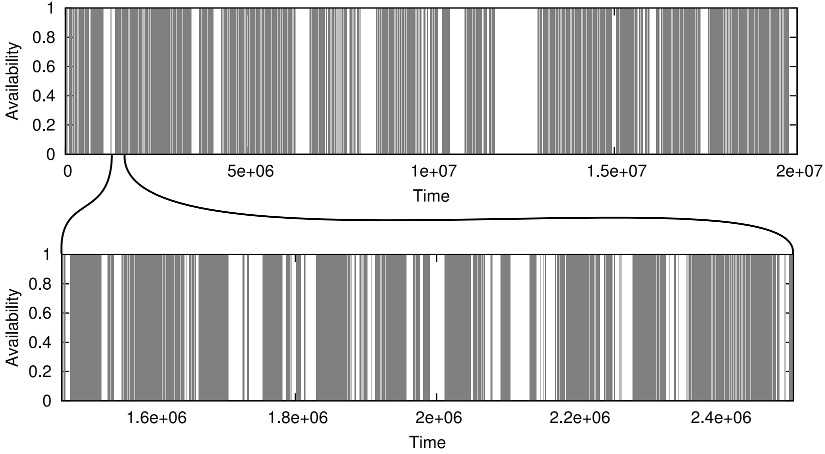
- Real BOINC availability trace file
  - Availability is either true or false
  - 8-month period, then 12-day zoom
  - One volunteer
- Plot with GNUPlot to a PDF (vector) file

Motivation (BOINC example)

- One volunteer client (top: 8-month, bottom: 12-day)
- Reasonable view, with a zoom for details



Motivation – trust the rendering?

Same vector file, two different views

$\rightarrow$ Different interpretation depending on the viewer

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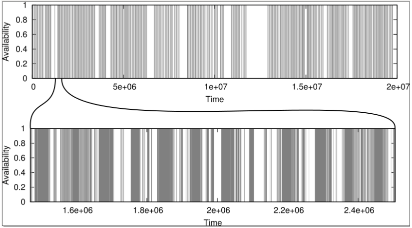

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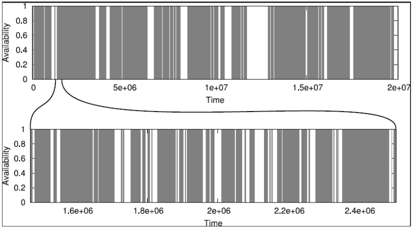

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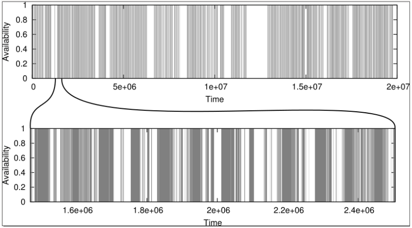

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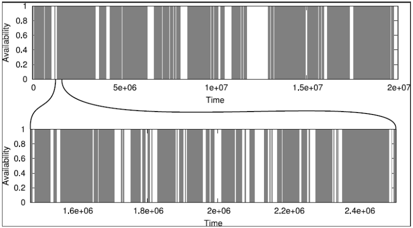
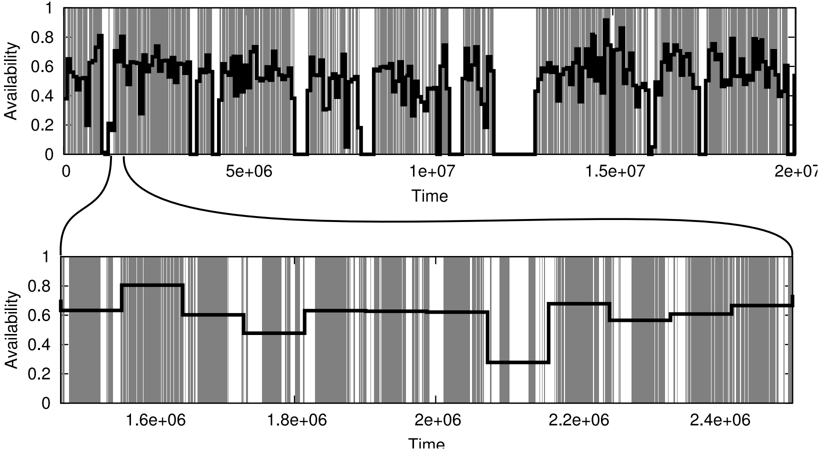


- Should we trust the rendering ?
  - No!
  - We need to make choices before visualizing data

Motivation → data aggregation

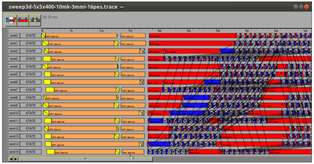
- 24-hour time integration



Space/Time views for trace analysis

- Widespread, useful, intuitive, fast adoption
- Space (vertical axis) and Time (horizontal)
- All trace events represented, causal order

Paje
http://paje.sf.net



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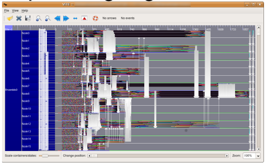

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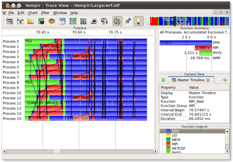

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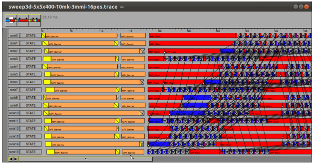

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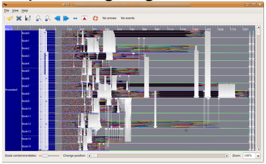

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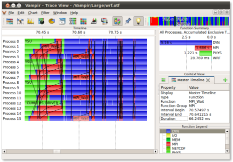
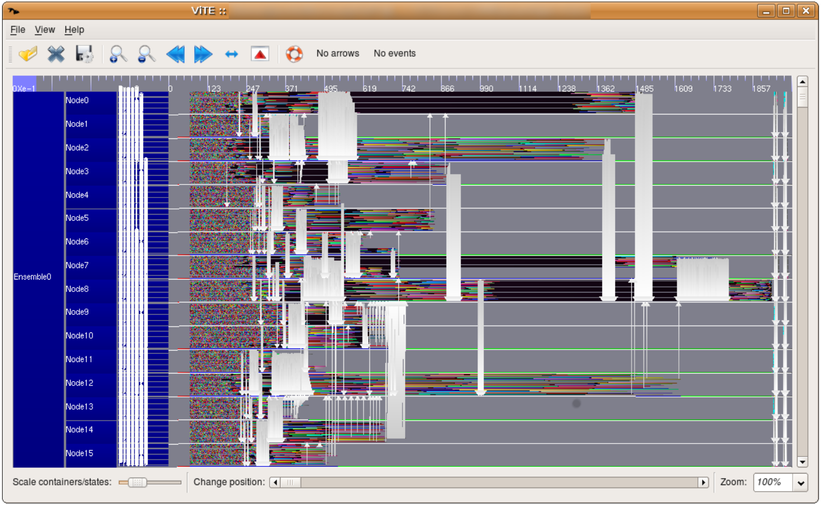


However...

- Also impacted by ever larger trace sizes
- Limited visualization scalability

Space/Time views – closer look (ViTe tool)

- Trust the OpenGL rendering, no data aggregation



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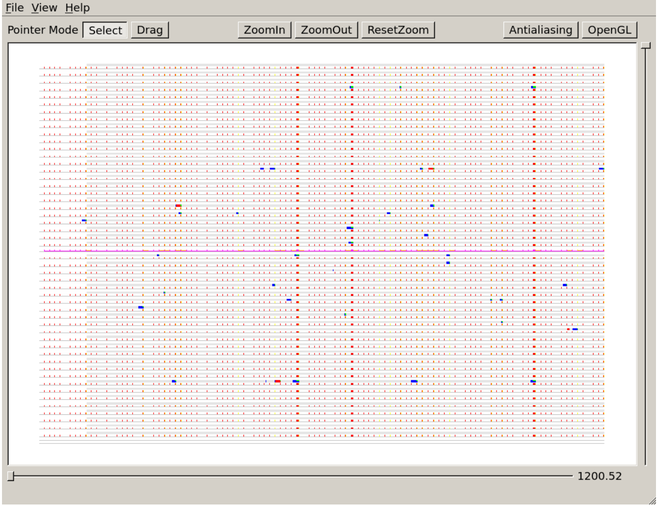
Space/Time views – closer look (new Pajé)

- Trust the two types of rendering
  $\rightarrow$ without or with OpenGL



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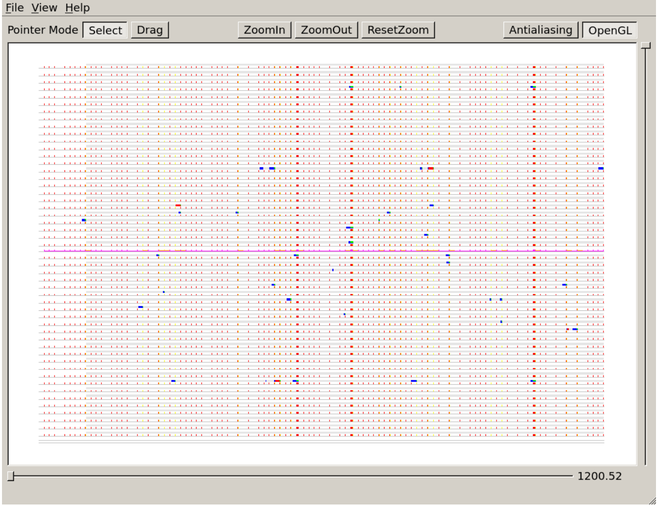
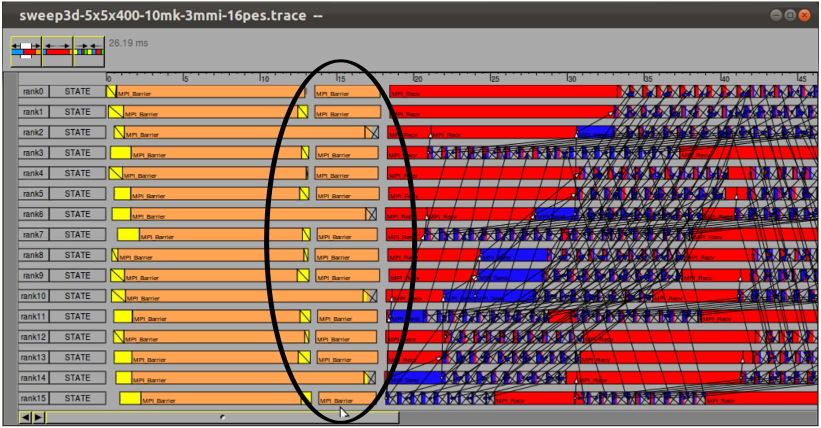


Space/Time views – closer look (old Pajé)

- Opaque aggregating filter (no user interaction)
  $\rightarrow$ Slashed rectangles represent time-integrated states
- Self-configure depending on temporal zoom



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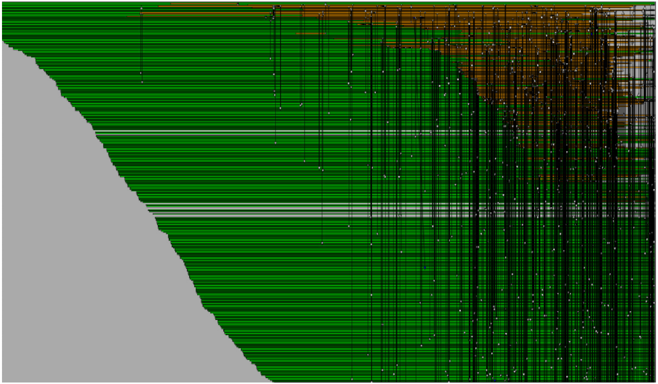
Space/Time views – closer look (old Pajé)

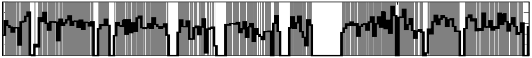
- Space dimension: one process per vertical pixel
  → at best, 1000 process represented at the same time



- Clustering algorithms by process behavior?
  → Remove similar processes and choose a representative

Introduction – summary and approach

- Data aggregation is key for large-scale visualization
  → Avoid graphical aggregation rendering
- Aggregated data may be more representative



- Note: Concerns with behavior attenuation
  - Aggregation may remove important details
  - Flexible aggregation: operators & neighborhood

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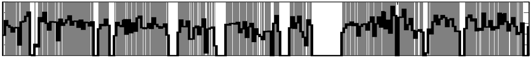

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Main idea:
Visualization techniques based upon aggregated data

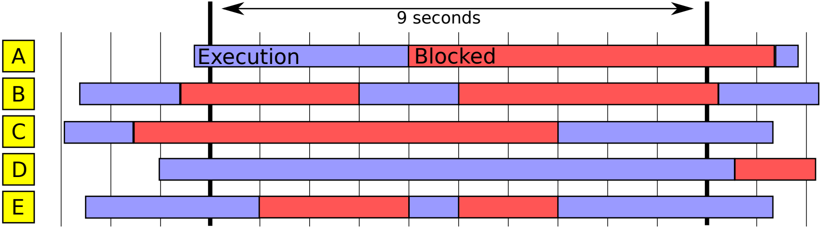
- Spatial and temporal trace aggregation
- Alternative visualization techniques
  - Squarified Treemap View
  - Hierarchical Graph View

Outline

1. Space/Time Trace Aggregation
2. Visualization techniques
   - Squarified Treemap View
   - Hierarchical Graph View
3. Some scenarios
4. Conclusion

Space/Time Trace Aggregation

- Temporal integration
  1. Time interval defined during the analysis
  2. Summary of events for each monitored entity



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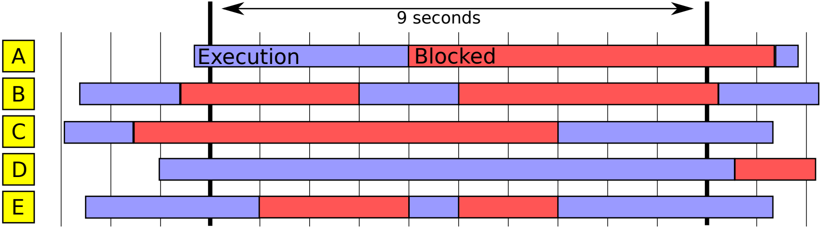


Time-integrated summary for processes

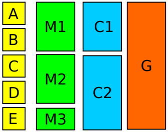
Numbers are in seconds (Execution, Blocked)

A=(4,5) B=(7,2) C=(3,6) D=(9,0) E=(4,5)

Space/Time Trace Aggregation

- Spatial integration
  1. Define a neighborhood for each monitored entity
  2. Apply an aggregating operator on the neighborhood

- Neighborhood as a hierarchy
  - Resource-based
  - Application groups
- Deeper the hierarchy → higher the quality



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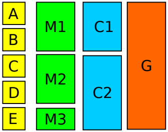
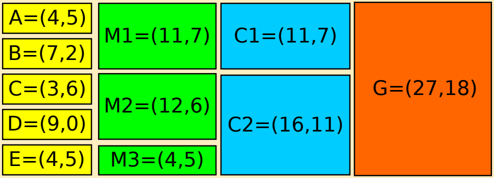


Space-integrated summary

Aggregating operator: addition (Execution, Blocked)



Alternative Visualization techniques

- Based on trace aggregation data
- Keep visualization scalability under control

Techniques

- Squarified Treemap View
  - Observe outliers, differences of behavior
  - Compare behavior
- Hierarchical Graph View
  - Pin-point resource contention
  - Correlate application behavior to network topology

- Design
- How time and space-aggregated data is represented
- An example

Squarified Treemap View – Basic concepts

- Scalable representation for hierarchies
  $\rightarrow$ when compared to node-link diagrams
  $\rightarrow$ better visualization scalability for large trees
- Complementary to the space/time view
- Hard to discern the structure of hierarchy
  $\rightarrow$ Borders help, but occupy space. Cushion treemaps?
  - Adopt the simple algorithm + interaction

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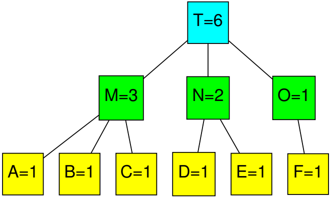
- Space-filling top-down recursive layout algorithm
  - Node value → space occupied in the screen
  - Squarified version → keeps rectangles ratio close to 1



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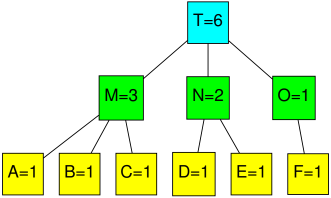

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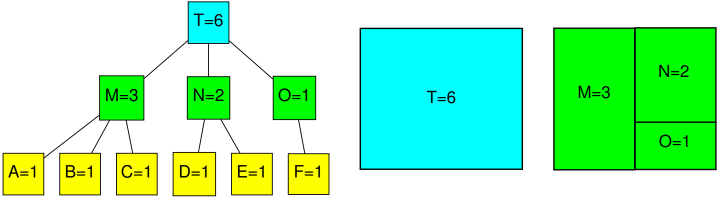

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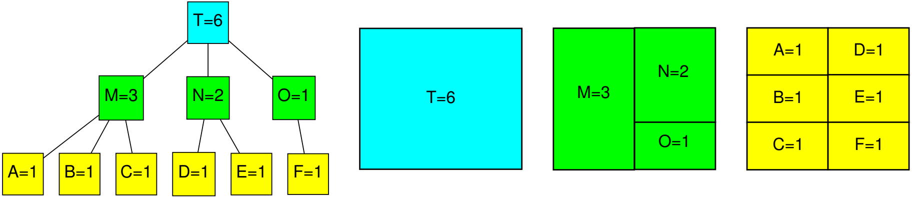
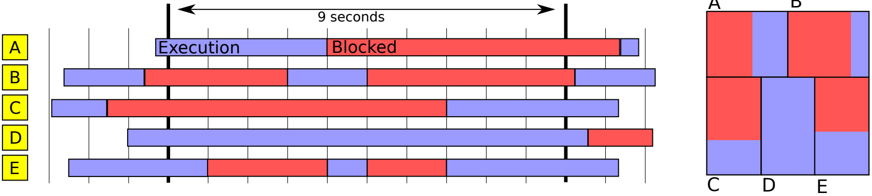


Squarified Treemap View – Aggregated Data

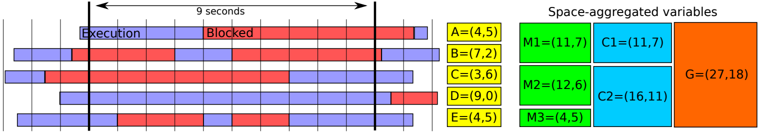
- Considering temporal aggregation only
  - Sum of all time-integrated data → node screen space
  - Each time-integrated variable → inner-node division



- Note: nodes might have different sizes
  → depends on the time-slice and the state values
- Time-slice changes → new treemap layout rendered

Squarified Treemap View – Aggregated Data

- Considering spatial-temporal aggregation



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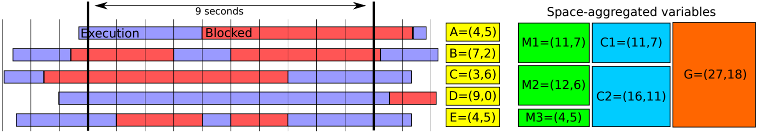

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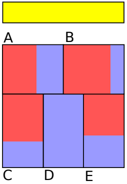

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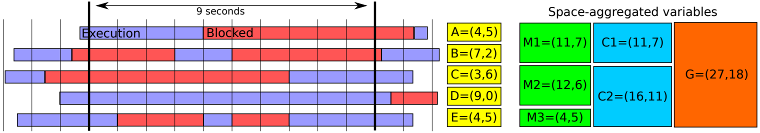

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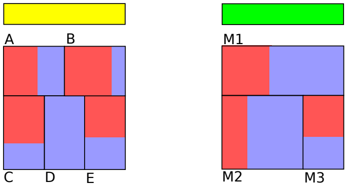

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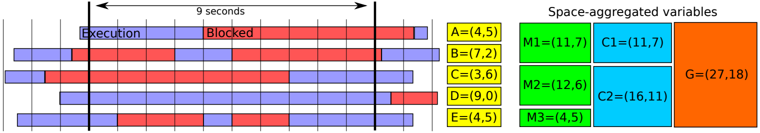

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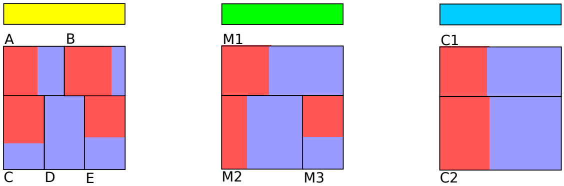

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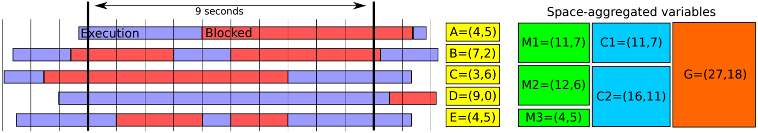

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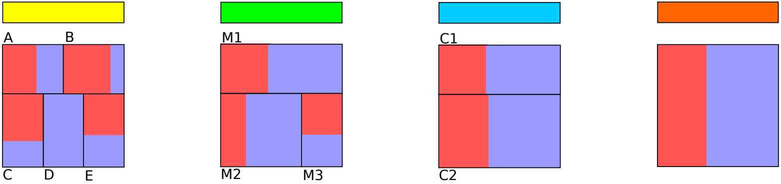

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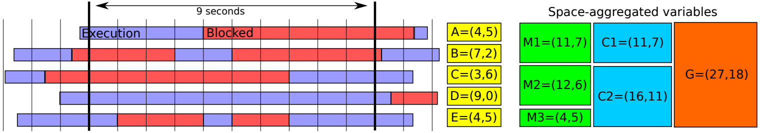

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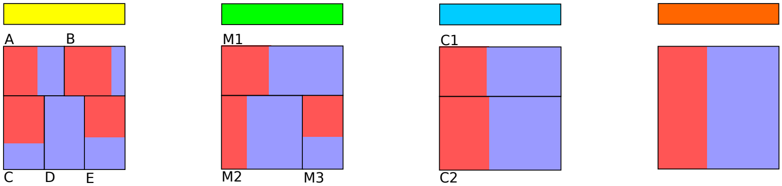
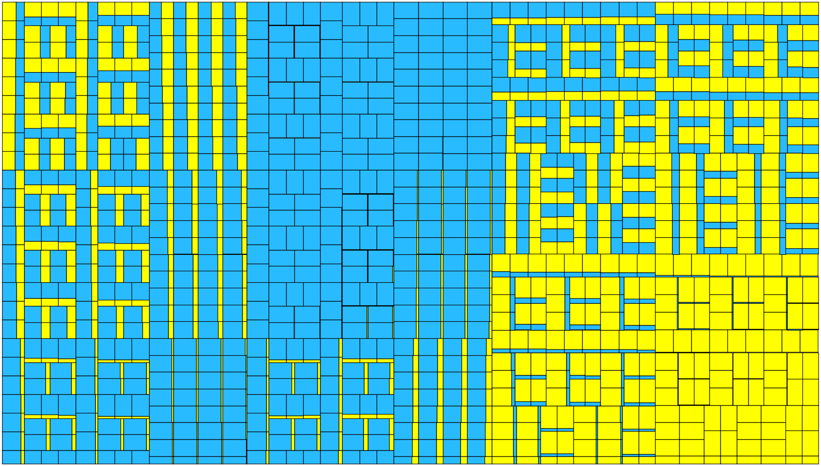


- The analyst decides
  - time-slice
  - hierarchy depth to draw

Squarified Treemap View – an example

- 1000 processes, in one of two states (synthetic)
- Aggregation level: 0, 1, 2, 3



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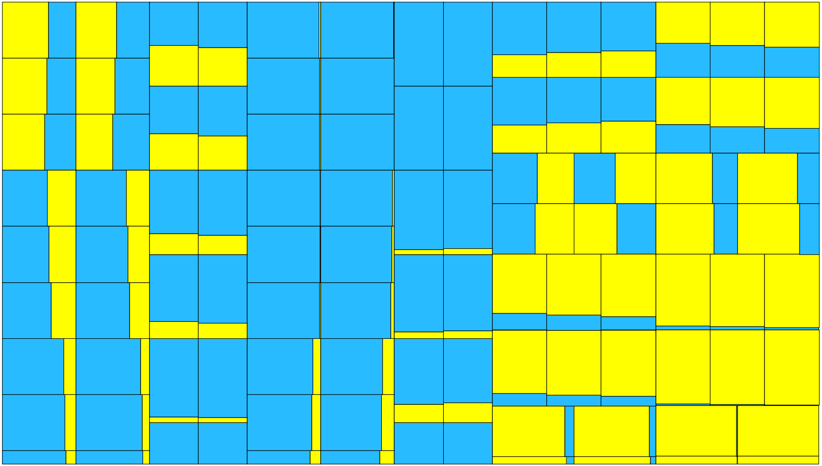

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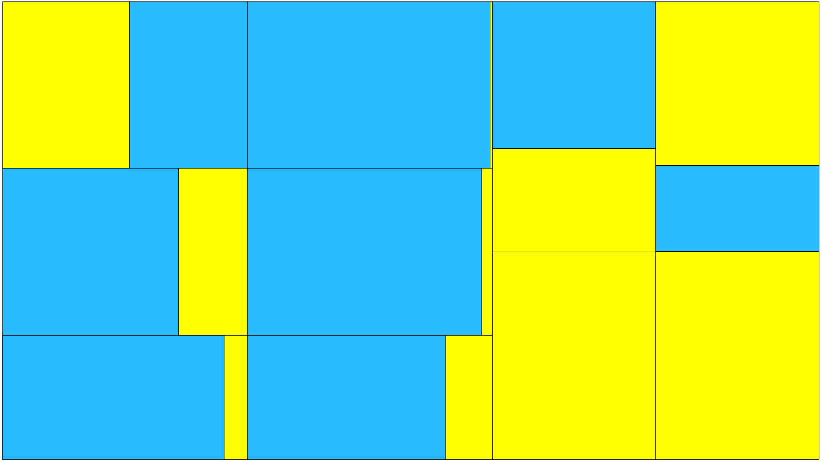

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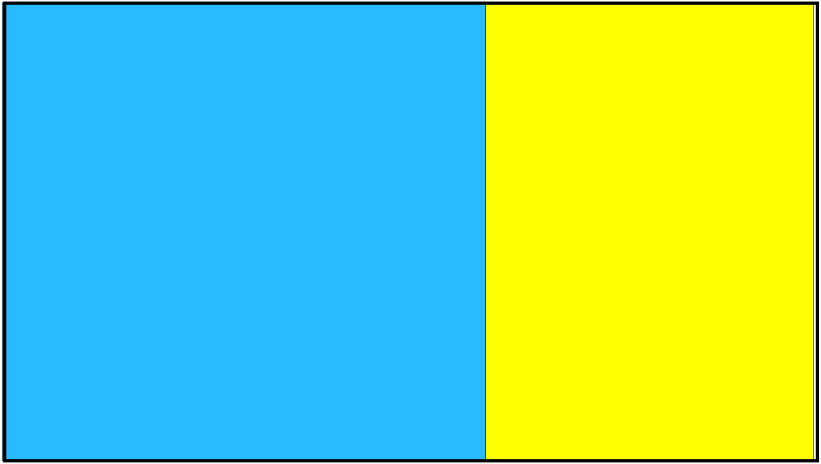
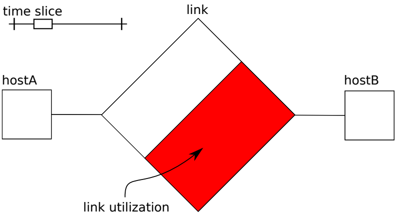


Hierarchical Graph View

- Scalable representation for graphs
  - Topology, with application-level metrics
  - Identify resource bottleneck in space and time
- Use spatial-temporal aggregated traces
- Interactive force-directed layout (Barnes-Hut algorithm)

Hierarchical Graph View

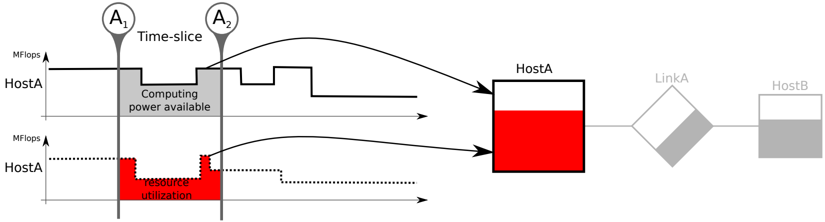
- Scalable representation for graphs
  - Topology, with application-level metrics
  - Identify resource bottleneck in space and time
- Use spatial-temporal aggregated traces
- Interactive force-directed layout (Barnes-Hut algorithm)
- Map trace metrics to geometrical attributes
  → Size, shape, filling, colors
  → Nodes: monitored entities
  → Edges: relationship among entities



Hosts → squares
Links → diamonds

Hierarchical Graph View - Aggregated Data

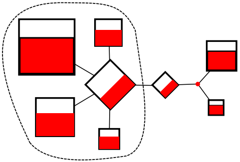
- Considering temporal aggregation only



- Graph changes → force-directed updates positions
- Time-slice changes → new layout is rendered

Hierarchical Graph View - Aggregated Data

- Considering spatial-temporal aggregation
  - Nodes are organized as a hierarchy
    - $\rightarrow$ Based on geo or logical location
    - $\rightarrow$ Application-dependent – get from traces
  - Analyst can control the level
- Aggregated representation
  - Many shapes depending on aggregated entities



Hierarchical Graph View - Aggregated Data

- Considering spatial-temporal aggregation
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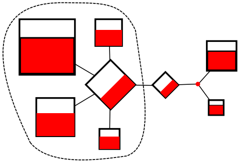

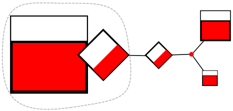

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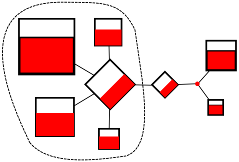

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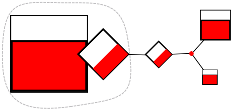

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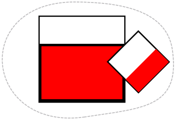

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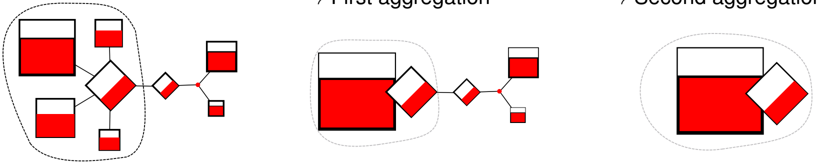
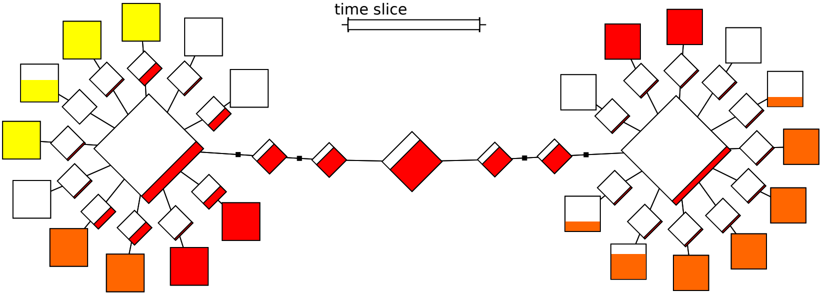


- Analyst decides
  - time-slice
  - the cut on the hierarchy (defining a new graph)

Hierarchical Graph View - an example

- Squares are hosts, diamonds are network links
  - Colors represent different applications
  - or parts of it (task type, phase)
- Two clusters interconnected by four network links
  - Cluster backbones have larger bandwidth capacity
  - Each host connected to the backbone by a private link



Some scenarios

1. BOINC fair sharing
2. Work stealing with KAAPI
3. Large scale treemap visualization
4. NAS-DT with graph view

Scenario 1 – BOINC fair sharing

- Setting: BOINC simulation (simulate the client side)
  - Two BOINC project servers with continuous jobs
  - 65 volunteers, must be fair between the two projects
  - Ten weeks, real availability traces from FTA
- Aggregation: whole time – all volunteer clients

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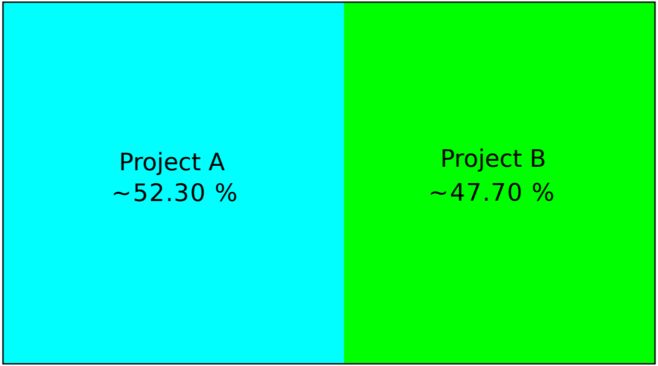

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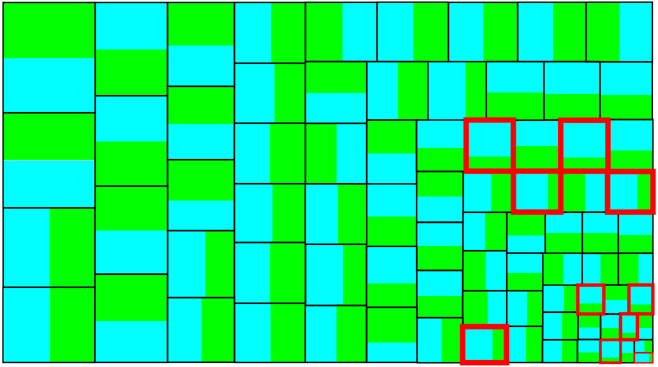

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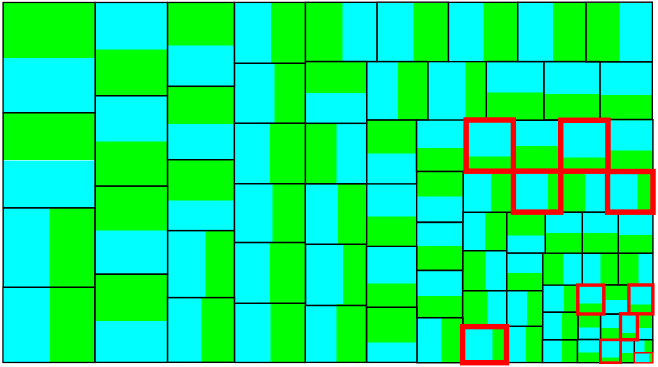
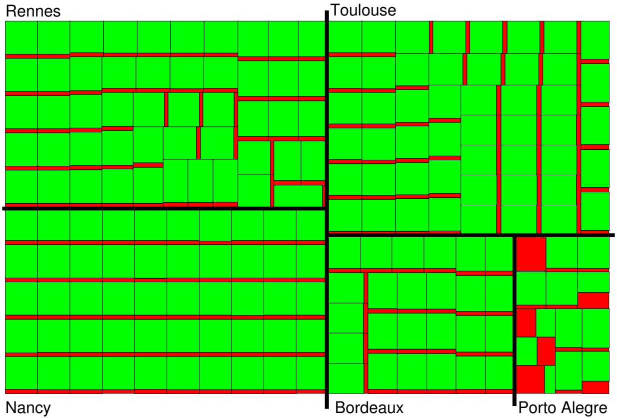


- Analysis: Small volunteer contribution → not fair

Scenario 2 - Work stealing with KAAPI

- KAAPI: load balancing through random work stealing
- 188 processes running on five clusters



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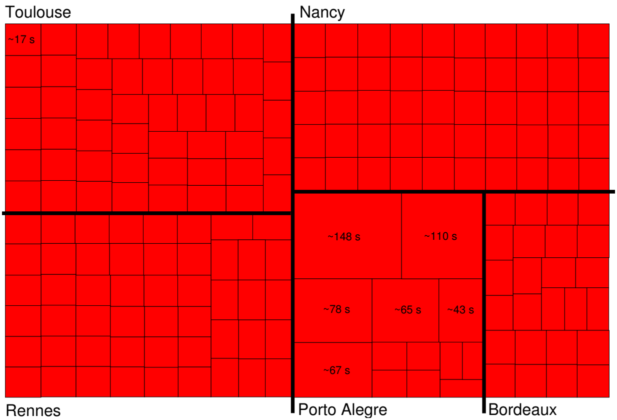

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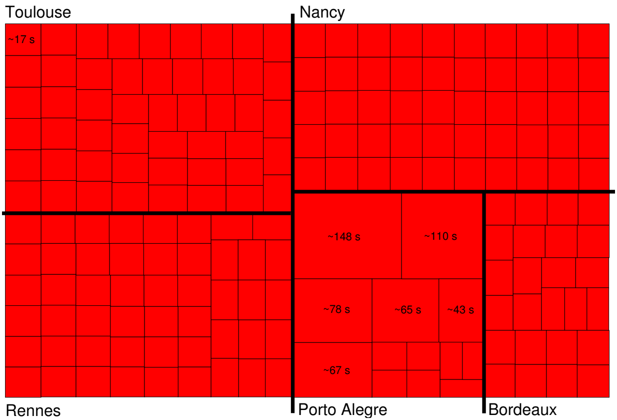
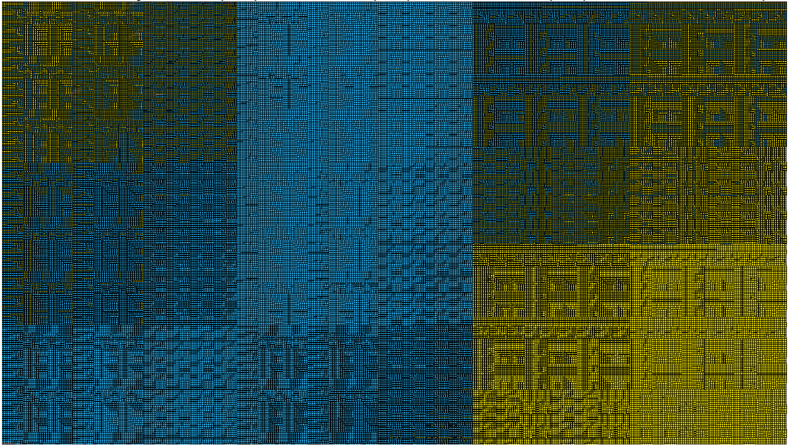


- Analysis: stealing requests depends on latency
  Porto Alegre – France: ~300 ms In France: ~10 ms

Scenario 3 - Synthetic, Large Scale

- Synthetic trace with 100 thousand processes
- Two states, four-level hierarchy
- Visualization artifacts without spatial aggregation

A Hierarchy: Site (10) - Cluster(10) - Machine (10) - **Processor** (100)



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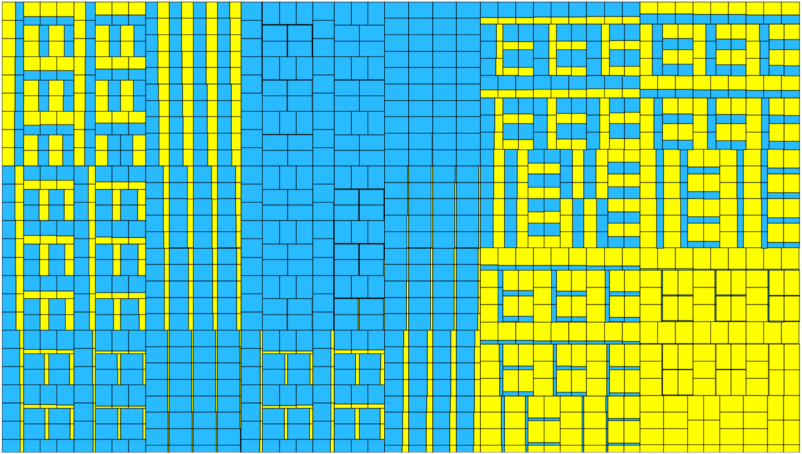

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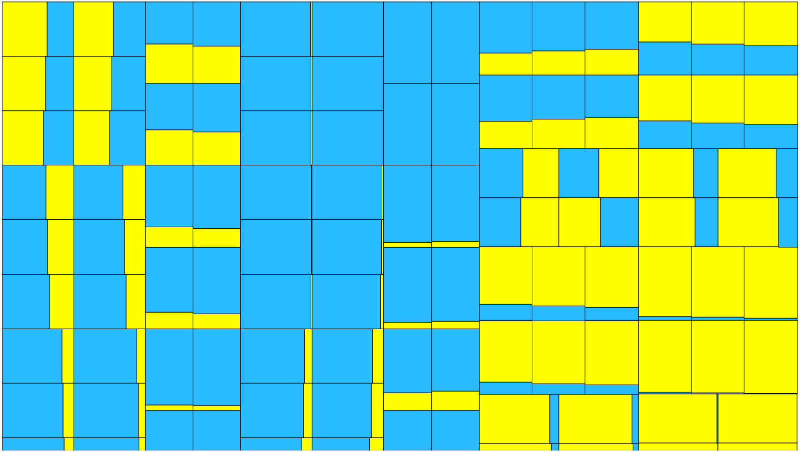

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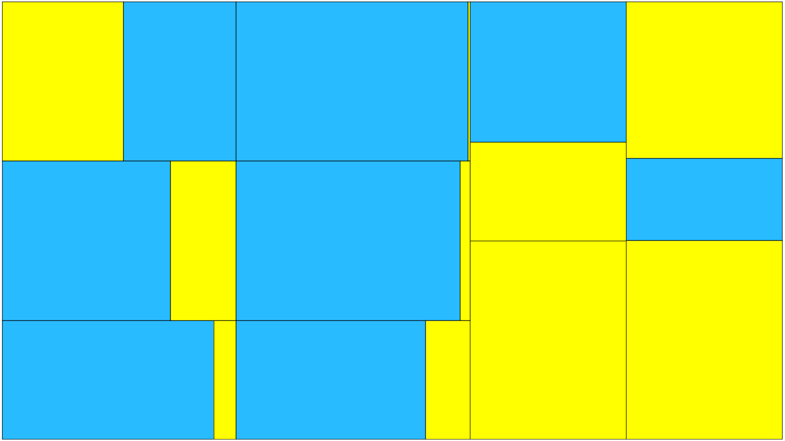

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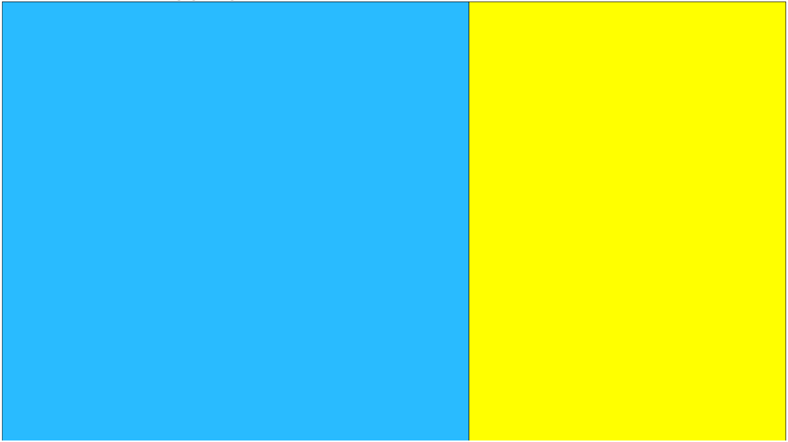
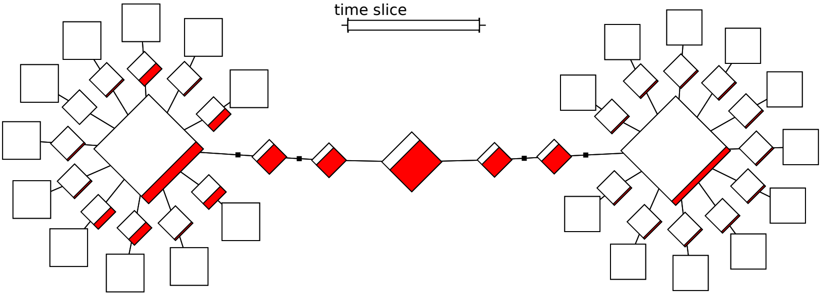


Scenario 4 - NAS-DT Class A WH

- NAS DT Class A White Hole algorithm
  → Traces from SMPI (Simulated MPI, part of SimGrid)
- Network topology – resource utilization by red filling
- Only temporal aggregation



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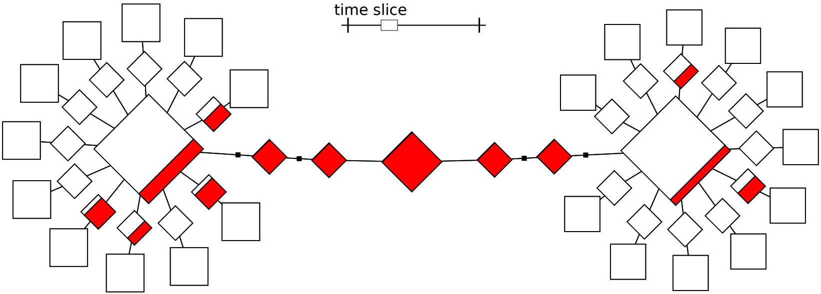

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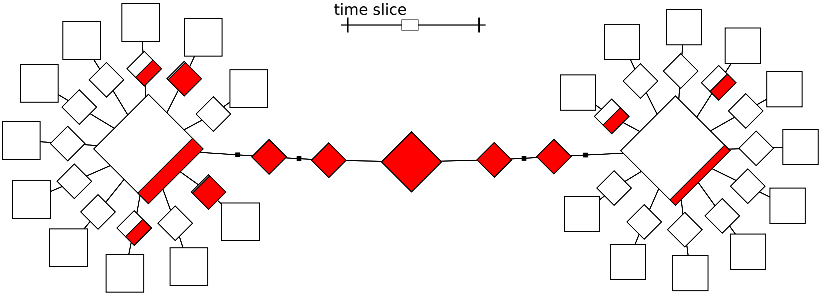

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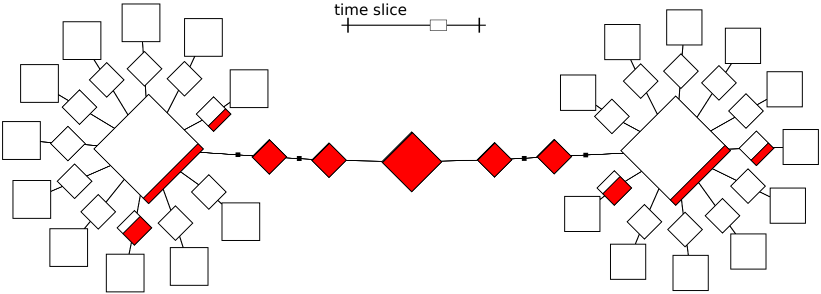

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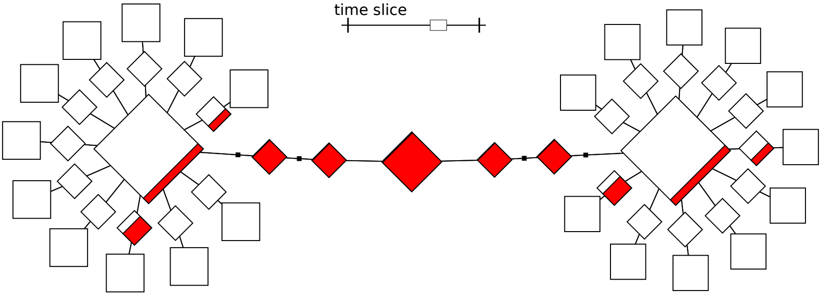
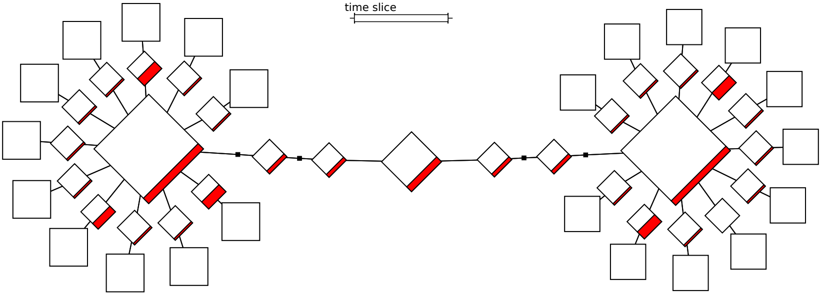


- Analysis: interconnection backbone is the bottleneck

Scenario 4 - NAS-DT Class A WH (second try)

- Another deployment with a different mapping
  $\rightarrow$ by changing the order of machines in hostfile
- Explore communication locality



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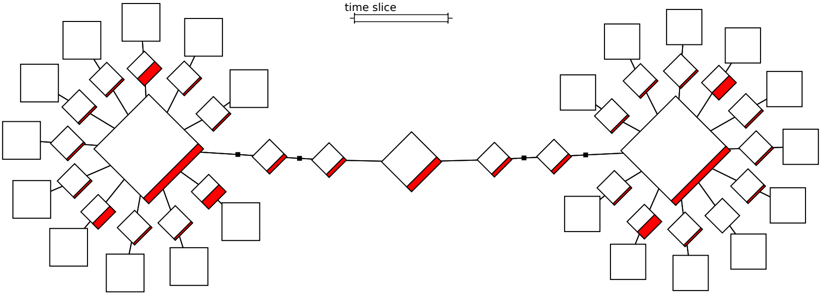

- Note: Small scale and easy scenario – but it is a start

Conclusion

- Data aggregation
  - Key to scale data visualization for analysis
  - No pre-defined or fixed parameters
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- Aggregation $\rightarrow$ behavior attenuation
  - Have to be able to find the right time/space level
  - Keep the analyst in control

Open-source tools

- Paje (Space/Time views, pie-charts), LGPL
  `http://paje.sourceforge.net`
  - Since 2000, GNUstep-based, written in Objective-C
  - Not only a monolithic visualization tool
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- Triva (Treemaps, Hierarchical graph), LGPL
  `http://triva.gforge.inria.fr`
  - Since 2007, GNUstep and Paje-based, also in Obj-C
    - Follows the Paje protocol
  - GNUstep runtime poses scalability problems

Future work

Technical

- Paje++ (or Paje2) – complete re-write in C++, Qt
- Viva – visualization tool (Treemap, Hierachical Graph)
  Also as a sandbox for developing new techniques
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Research

- Better aggregation algorithms – for performance
- What about other aggregation operators?
- Aggregated data $\rightarrow$ space/time view

Thank you for your attention

- Some references
  - Detection and Analysis of Resource Usage Anomalies in Large Distributed Systems Through Multi-scale Visualization. Lucas Mello Schnorr, Arnaud Legrand, Jean-Marc Vincent. Concurrency and Computation: Practice and Experience. Wiley. 2012.
  - A Hierarchical Aggregation Model to achieve Visualization Scalability in the analysis of Parallel Applications. Lucas Mello Schnorr, Guillaume Huard, Philippe Olivier Alexandre Navaux. Parallel Computing. Volume 38, Issue 3, March 2012, Pages 91-110.

- More information
  → `http://mescal.imag.fr/membres/lucas.schnorr/`

- INFRA-SONGS Project (WP-7)
  `http://infra-songs.gforge.inria.fr/`
  Simulation of Next Generation Systems
  WP-7: Visualization and Analysis