Visualization for Performance Debugging of Large-Scale Parallel Applications

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à la mémoire de Jacques Chassin de Kergommeaux

1 Introduction
- Motivations
- Examples

2 Trace Fundamentals
- Fundamentals
- Pajé

3 Performance Analysis
- Three-Dimensional Model
- Temporal & Spatial Aggregation Model

4 Synthesis
- Research directions

Motivations

Scientific context

- Complex parallel/distributed programs
- Potentially large size parallel applications.
- Executing on large size parallel systems:
  - Distributed systems
  - Clusters and Grids
  - Desktop grids, P2P systems...

Keypoints

- Distributed heterogeneous resources
- Dynamicity of the architecture
- Scalability (huge amount of data)

General Objective

Help users find performance errors:

- Visualization of parallelism, identify synchronization overheads,
- Usage of resources, identify bottlenecks,
- Behavior analysis method.

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Based on:

- Execution model : user events,
- Infrastructure model : Measurement environment
- Visualisation model : graphical objects.

Visualization of parallel program execution

Who ?

Program designer, Program certifier, $\cdots$

$\cdots$ Parallel programs vendors

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Why ?

- Program debugging,
- Quantitative debugging (performance evaluation),
- Dimensionning and performance tuning

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How ?

- Graphical representation of the parallel execution
- Interactive representation (exploration)
  - zoom in and out on time, infrastructure, on objects
  - compute statistics

Methodology

Execution model

- Abstraction of the parallel execution : state / event model
- Observability of states / Practical interest of states
- Quality of observation (interaction tracer/application)

Environment model

- Structured set of resources (architecture)
- Model of time : Datation model

⇒ **Manipulation language of resources, states and events**

Collaboration (a not so short story)

UFSM, UFRGS, U. of Grenoble, INRIA

Introduction - Existing Tools/Techniques

- Statistical Techniques
  - ParaGraph (1990) – bar charts, utilization Count
  - Pablo (1993) – bar charts + 3D scatter plot
  - Paradyn (1995) – histograms
- Behavioral Techniques
  - ParaGraph (1990) – Gantt-chart
  - Vampir (1996) – time-line system view
  - Jumpshot (1999), Pajé (2000) – space-time
  - Virtue (1999) – virtual reality to performance analysis
  - Kojak, ParaProf (2003) – Call Graph
- Structural Techniques
  - ParaGraph (1990) – network display / hypercube
  - Cray Apprentice (2007) – tree view of imbalances

Main difficulty

Large scale systems

- Large number of objects
- Complexity of views
- Level of abstraction
- Dynamicity of the observed infrastructure

Multithreaded Applications (1999)

Distributed Middleware

Distributed Middleware (2)

Distributed Middleware (3)

Distributed Middleware (4)

Distributed Middleware (5)

Consensus in ad-hoc networks

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Coordinator Crashes

Multi-Agent Systems

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Performance Analysis

- Collect performance data
- Process collected data
- Visualize resulting data

Performance data collection

- Sampling

  let the system run, and from time to time, take a look at the state of the system

- Event-driven

  get informed of interesting changes in system state

Performance data collection

- Sampling

  let the system run, and from time to time, take a look at the state of the system
- Event-driven

  get informed of interesting changes in system state
  - Counting

    count number of times event happened
  - Timing

    accumulate time passed between pairs of events
  - Tracing

    register events for later processing

    usually also registers sampling data

Some tracing problems

- Clock synchronization
- Timer resolution
- Intrusion

  time / memory / I-O / influence in program behaviour
- Observability

  level of abstraction
- Matching independently captured events

  different machines or abstraction levels
- Amount of data
- Bufferization
- Trace file format

Trace data processing

- Merge / reorder
- Complement information
- Filter
- Reduce
- Prepare data for visualization

Pajé

- Generalize visualization tool, remove semantics
- Trace file contains
  - hierarchy of containers
  - each can contain combination of containers and visualizable entities
- Entities can contain extra data, used for filtering and reducing; user knows semantics
- Tool keeps original data and processed data, user chooses views

Pajé

Possible entity types

- **event** to represent events that happen at a certain instant
- **state** to represent that a given container was in a certain state during a certain period of time
- **link** to represent a relation between two containers that started at a certain instant and finished at a possibly different instant
- **variable** used to represent the evolution in time of a certain value associated to a container

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Performance Analysis

1. Analysis considering network topology

2. Large-scale analysis
   - How to analyze thousands of processes?
   - Temporal & Spatial Aggregation
   - Treemap representation

- Execution Platform: Grid'5000
  - Distributed resources in France
  - Highly hierarchical network organization
  - Limited heterogeneity – clusters

3D Model – Basics

- Structural Representation – 2D
- Vertical dimension is time – 1D
  - Objects' Behavior Evolution
  - States and Links

- Interaction Techniques

3D Model - Visualization

- How objects are represented in 3D

3D Model - Visualization

- How objects are represented in 3D
- Rendering the Network Topology + Comm. Pattern

3D Visualization - Communication Patterns

- Differences from the space-time diagram

Ring Communication Pattern

Fully-Connected

Star

3D Visualization - KAAPI Trace

- Fibonacci Application
- 26 processes, two sites, two clusters
- Lines represent steal requests
- Different number of communication between clusters
  - beggining → big tasks, less communication
  - end → smaller tasks, more communication

3D Visualization - KAAPI Trace

- 60 processes, two sites, three clusters
- Total execution time of a KAAPI fibonacci application
- Observe number of requests in time

3D Visualization - KAAPI Trace

- 200 processes, 200 machines, two sites, five clusters
- Annotated manually with bandwidth limitations

Initial Execution of Application with Link Properties

Interconnection becomes bottleneck, possible hints to better allocation

3D Visualization - KAAPI Trace

- 2900 processes, four sites, thirteen clusters

End of Execution

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Temporal & Spatial Aggregation Model

- Enable large-scale trace analysis
- Visualy compare entities behavior
- Detect global and local characteristics

Steps of the Model

1. Hierarchical Monitoring Data
2. Temporal Aggregation
3. Spatial Aggregation
4. Treemap representation

Temporal Aggregation - Basics

Objective: annotate leaves of the hierarchy

- Time-slice definition
- Summary of trace events on the interval
  - States, Variables, Links, Events, ...

Temporal Aggregation - Example

Temporal Aggregation - Example

(Blocked, Executing)

Spatial Aggregation

- Explore the hierarchical organization
- Create aggregated values at intermediary levels

Aggregation Functions

- add, subtract, multiply, divide, max, min, median, ...
- Depends on
  - what type of value the leaves have
  - the desired statistical result

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Visualization of the Approach - Treemaps

- Scalable hierarchical representation
- Top-down drawing algorithm
- For a given node, split screen space among children

Original algorithm has several evolutions

- Squarified treemap is used here
- Keeps rectangles as close to squares as possible

Treemap to view the Aggregated Hierarchy

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Treemap Visualization - Description

Time-Slice and Aggregated Hierarchies

- Interaction Techniques: mouse wheel, mouse over
- Detailed information is available in the status bar

Treemap Visualization - KAAPI Trace

Run and **RSteal** states, 2900 processes, 310 processors

Treemap Visualization - Large-Scale

- Synthetic trace with 100 thousand processes
- Two states, four-level hierarchy

Treemap Visualization - KAAPI Trace

- 400 processes, 50 machines, one site
- 8 processes per machine
  - Overload of some machines with 2 CPUs
  - Unusual amount of time in Steal state
- Machines with 4 CPUs show normal behavior

Treemap Visualization - KAAPI Trace

- 188 processes, 188 machines, five sites
- Different behavior at Porto Alegre
- Probably due to the interconnection
  - Latency for Grid'5000 in France: ~10 ms
  - Latency between Porto Alegre and France: ~300 ms
- More time spent in work stealing functions

Treemap Visualization - MPI Trace

- Traces from the EP application – NAS Benchmark
- 32 processes – time spent in each MPI operation
- Init and Barrier views indicate a linear implementation

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Conclusion

Concepts

- Trace of parallel/distributed applications
- Multi-level trace
- Structural informations

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Algorithmic solutions

- Trace collection (quality of tracers, time estimation...)
- Simulation engine based on the state/event model
- Visualization engine (interactivity, extensibility, scalability)

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Case studies

- Parallel systems (MPI, Kaapi,...) Distributed middlewares, Wireless networks, Multi-agent systems,...
- Industrial application :Embedded systems, Jboss analysis, resilient protocols

Research directions

Scalability

- Aggregation : in time, space, structure (level, operators,...)
- Clustering : criteria of clustering

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User capabilities

- Observation environment : instrumentation, information synthesis
- Visualization environment : visual objects manipulation (time, objects, or structure selection), coherent multiple views

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Global properties and trace mining

- Query language for traces (filtering/aggregation/selection)
- Automatic data mining in the trace (patterns, properties)

Bibliography

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Thanks for your attention
The slides of the tutorial will be at
`http://www.inf.ufrgs.br/~lmschnorr`

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