Tracing and Monitoring Tools for Distributed Multi-Core Systems Project
State of the Art Meeting

Trace Abstraction and Correlation Track

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Agenda

- Introduction
- What is and Why Trace Abstraction?
- Review of Existing Trace Abstraction Techniques
- Proposed Trace Abstraction Approach
- Conclusion and Future Direction

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- **Introduction**
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Introduction

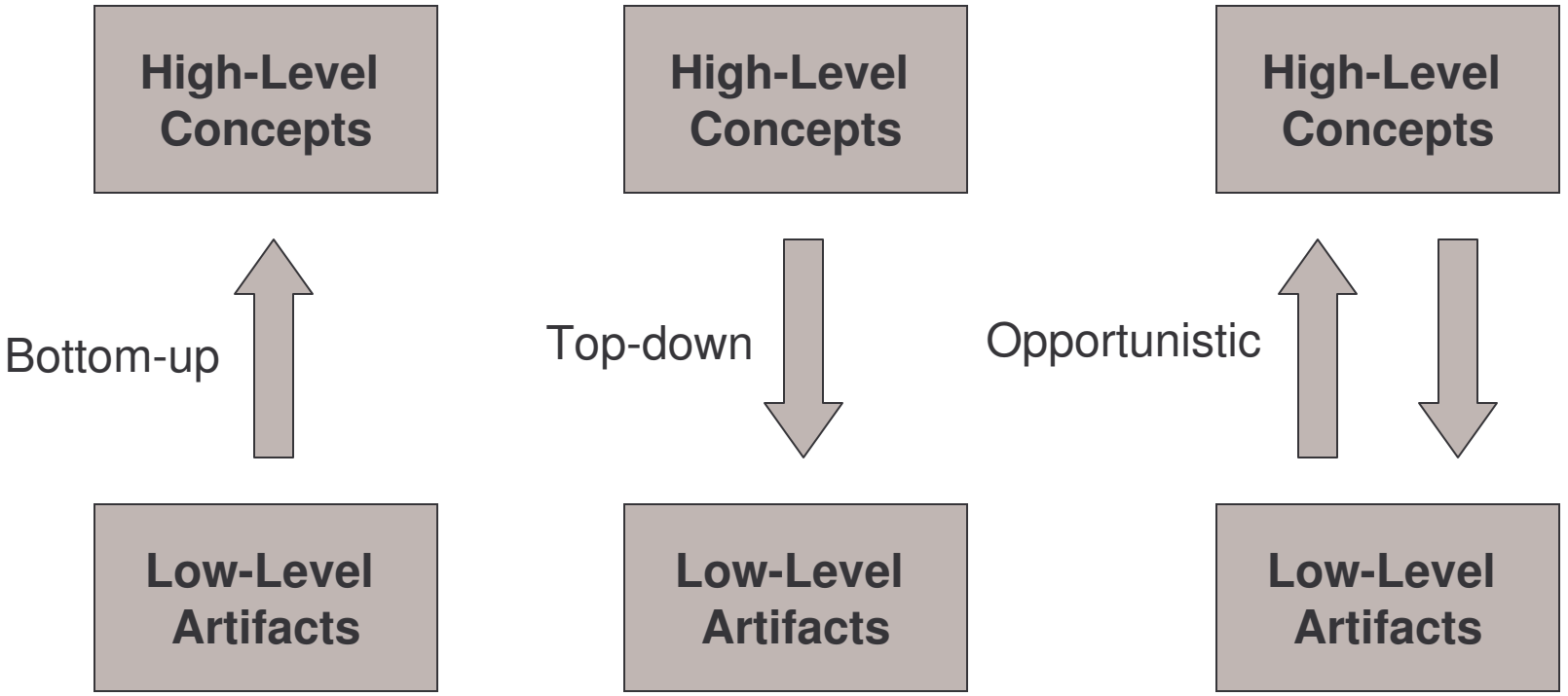
- Exploration of execution traces can help in a variety of applications such as:
  - Understanding why an unexpected behavior occurred (design faults, attacks,…?)
  - Understanding how a particular feature is implemented
  - Detecting causes of performance bottlenecks
  - Comparing traces from multiple versions of the system
  - Etc.
- Traces, however, tend to be excessively large and hard to understand.
  - Especially low-level, event-based, system call traces!

What is Trace Abstraction?

- A way to reduce the size of traces by abstracting out their main content
  - Two traces may look different but tell the same story
    - We are interested in the story and not the details
- The process of extracting high-level concepts from low-level trace events to facilitate the understanding and analysis of trace content

How People Understand System Artifacts?

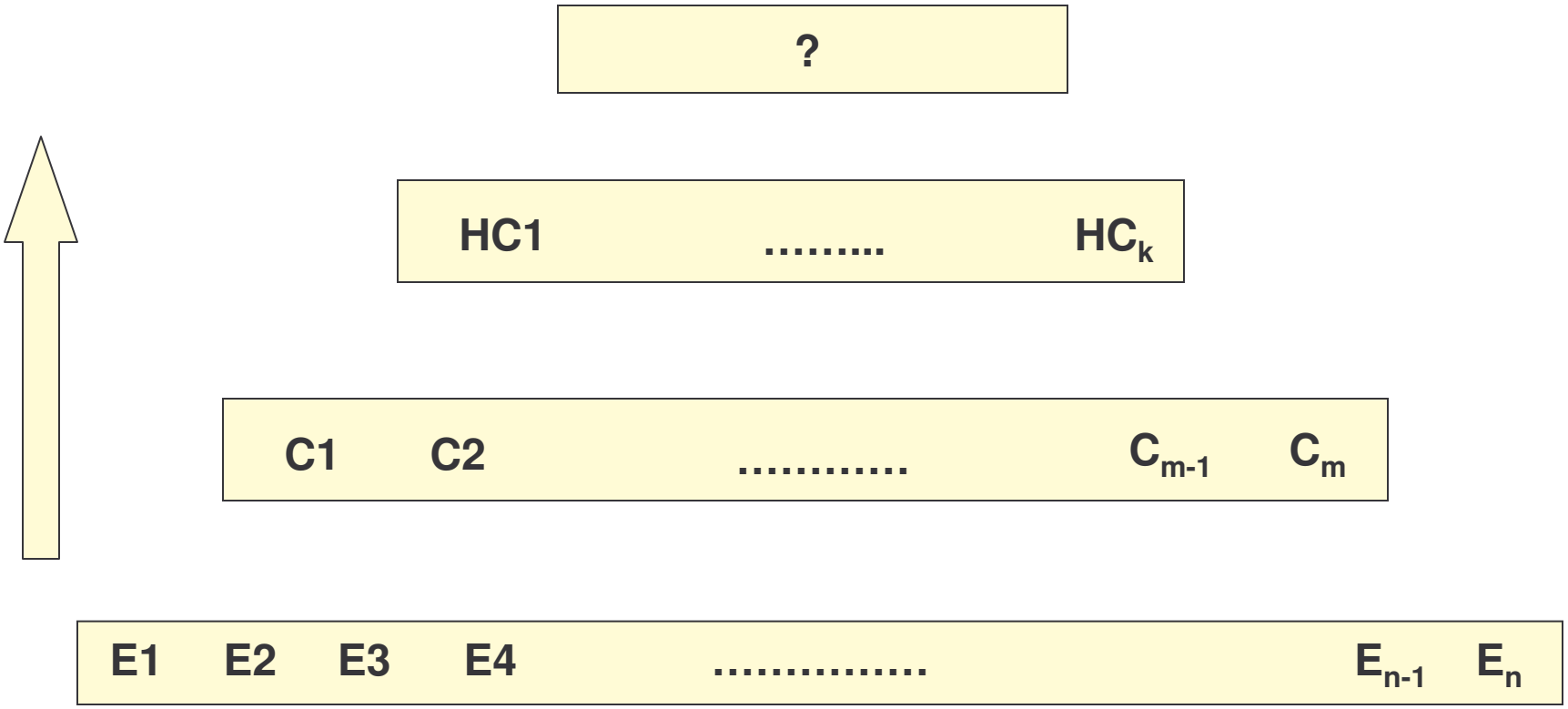
- Three strategies (based on empirical studies):



Trace Analysis: Trace Correlation

- Automatically comparing traces can help many applications:
  - Understanding how a system evolves by comparing traces of subsequent versions
  - Comparing traces for system health check
    - Important for detecting “zero-day” attacks
    - Security and self-healing systems
  - Very hard to do with low-level, event-based, system call traces!

Different Levels of Abstraction



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- Introduction and Motivations
- What is Trace Abstraction?
- **Review of Existing Trace Abstraction Techniques**
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Review of Existing Trace Abstraction Techniques

- We surveyed several trace analysis techniques and tools in various areas:
  - Performance analysis, development and debugging, software maintenance and program comprehension
- Examples of tools that have been surveyed:
  - Low-level trace analysis tools:
    - LTTV, Intel VTune, SystemTap, WindRiver Workbench, Zealcore System Debugger, etc.
  - High-Level trace analysis tools
    - ISVis, Jinsight, Ovation, SEAT, AVID, Scene, Shimba, Program Explorer, Collaboration Browser, AVID, OSE, TPTP, VET

Key Trace Abstraction Techniques

- Pattern detection
- Filtering of noise
- Sampling
- Visualization Techniques

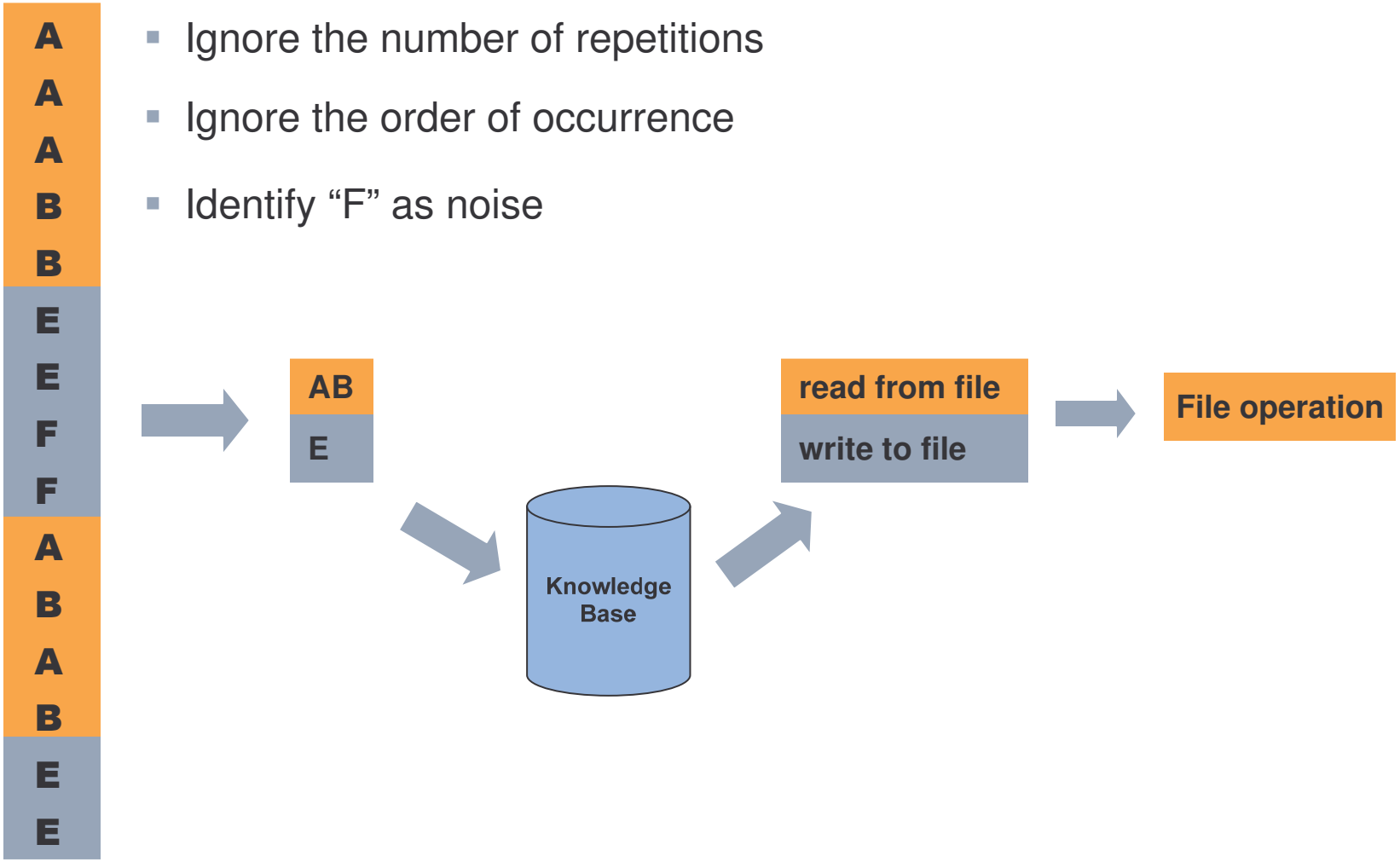
Pattern Detection Techniques

- A trace pattern is defined as a sequence of events that occurs repetitively but non-contiguously in several places in the trace.
- The more patterns in a trace, the less time is required to understand its content
  - We do not need to understand the same sequence twice!

More about Patterns

- Instances of the same pattern do not need to be identical
  - In fact, exact matching never leads to good abstraction!
  - Matching criteria need to be defined to enable generalization of a trace content
- Ideally, an extracted trace pattern should correspond to an abstract concept
  - E.g. a user identifiable computation of some feature

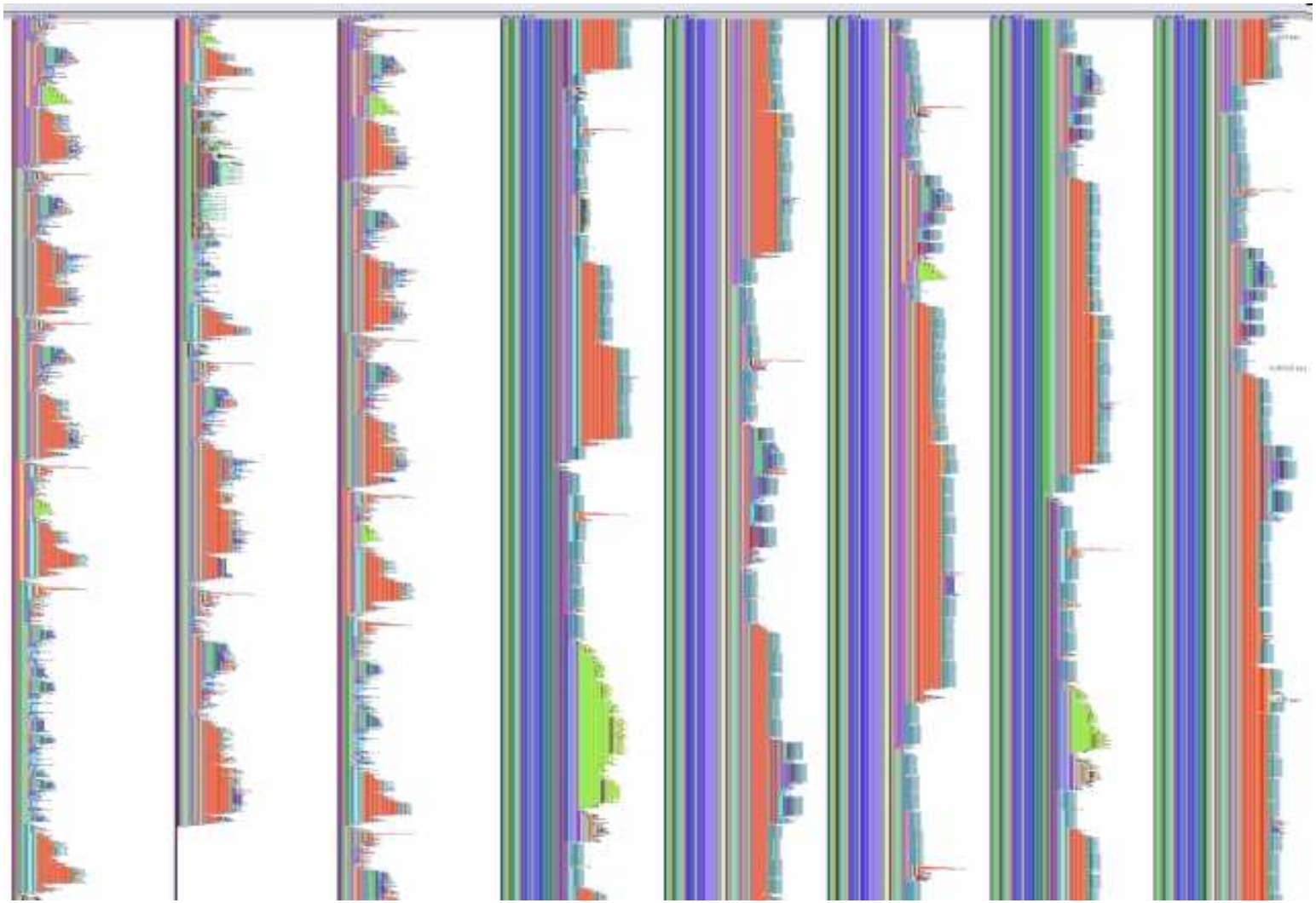
Example of Using Patterns



- Ignore the number of repetitions
- Ignore the order of occurrence
- Identify “F” as noise

Jinsight Pattern View (DePauw et al. 2004)

Part of IBM Rational® App. Developer for WebSphere® Software.



Pattern Matching Criteria

- Many pattern matching criteria have been proposed
  - Most of them can be applied to system call traces
  - De Pauw et al., Jerding et al., Richner et al., Systä et al, Hamou-Lhadj and Lethbridge, Bennett et al., etc.
- Examples:
  - Ignoring number of repetitions
  - Ignoring the order of occurrences
  - Treating a sequence of events as a set
  - Ignoring event information
  - Measuring the distance between two sequences
  - Etc.

Pattern Detection in Practice

- Various matching criteria have been used successfully in various studies:
  - Locate places in the system where enhancements are needed (Jerding et al.)
  - Helping debugging and fiingx system defects (Systä et al.)
  - Extracting component collaboration from traces (Richner et al.)
  - Recovery of high-level diagrams from traces (Hamou-Lhadj and Lethbridge)
  - Locating causes of performance bottlenecks (De Pauw et al.)

Detection and Filtering of Noise

- Traces often contain elements (noise) that are not needed at higher levels of abstraction
- What can be considered as noise depends on the objective of the analysis and the type of traces
  - LTTng traces contain many low-level memory management events that may not be needed at a high level
  - An example of noise in routine call traces are utilities and implementation details

Techniques for Detecting Noise

- Detection of noise can be user-guided or based on any available documentation
- A heuristic approach can also be used:
  - Frequency of the events
  - Order of occurrence
  - Dependency relationship

Sampling

- Sampling is also used to reduce the size of traces during its generation
- Several sampling criteria that can be used to generate small traces (Walker et al., Kuhn et al.)
  - Time-based sampling
  - Event-based sampling
  - Heuristic-based sampling
- The challenge is to find adequate sampling parameters

Trace Abstraction Based on Visualization Techniques

- Many tools have been developed to help analysts study execution traces
  - A set of features that visualize the traces and enable user interactions
  - Features categorized into:
    - Presentation Features: How trace is displayed?
    - Interaction Features: What can the user do with the system?

Presentation Features

- **Layout:** Defining the standard through which a trace is laid out (lines, points, graphs, etc.)
- **Multiple Linked Views:** Providing a number of views that are linked together
- **Visual Attributes:** Using colors and shapes
- **Labels:** Labeling events
- **Animation:** Supporting animation

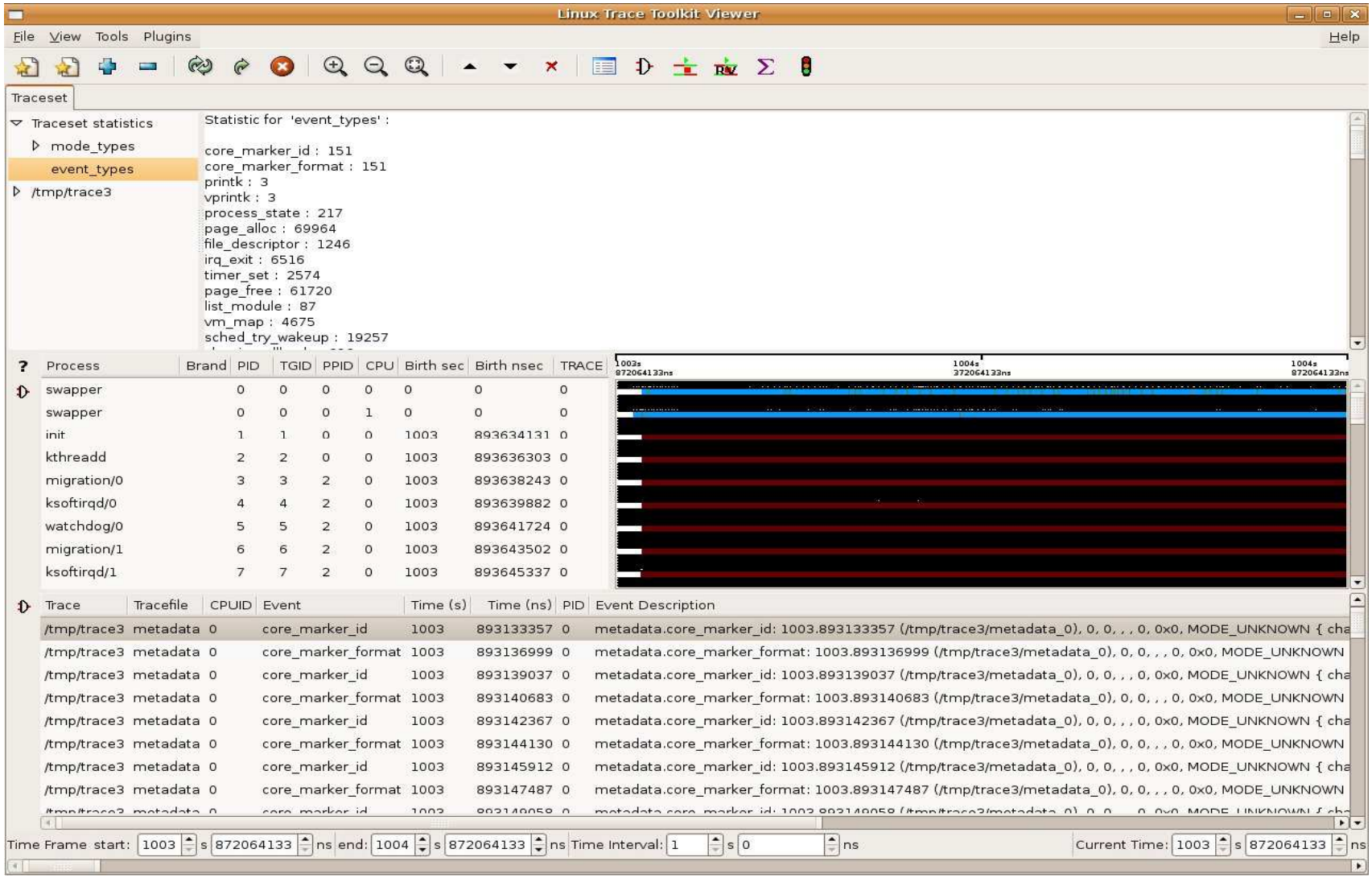
Interaction Features

- **Selection:** Selecting elements to manipulate, filter, or slice
- **Component Navigation:** Navigating between components and instances
- **Focusing:** Providing techniques such as: collapsing, partitioning, etc.
- **Zooming and Scrolling:** Enlarging or reducing the size of the event stream, moving up, down, left or right
- **Querying and Slicing:** filtering information, and selecting parts related to the selected component
- **Grouping:** Grouping objects, messages, repeated patterns
- **Annotating:** Describing grouped components, to store user notes while exploring the diagram
- **Highlighting:** Highlighting parts of the event sequence
- **Hiding:** Providing the ability to hide information

LTTV: Linux Trace Toolkit Viewer

- LTTV is provided to help studying the trace by visualizing it and providing a number of views:
  - The Statistic View displays statistics about the trace, the events' types, the processes, and the CPU
  - The Control Flow View provides an overall view of the trace, which helps developers to detect patterns that are recognized as lines with similar lengths and colors
  - The Detailed Event List View displays the list of events related to each process, like entry or exit events

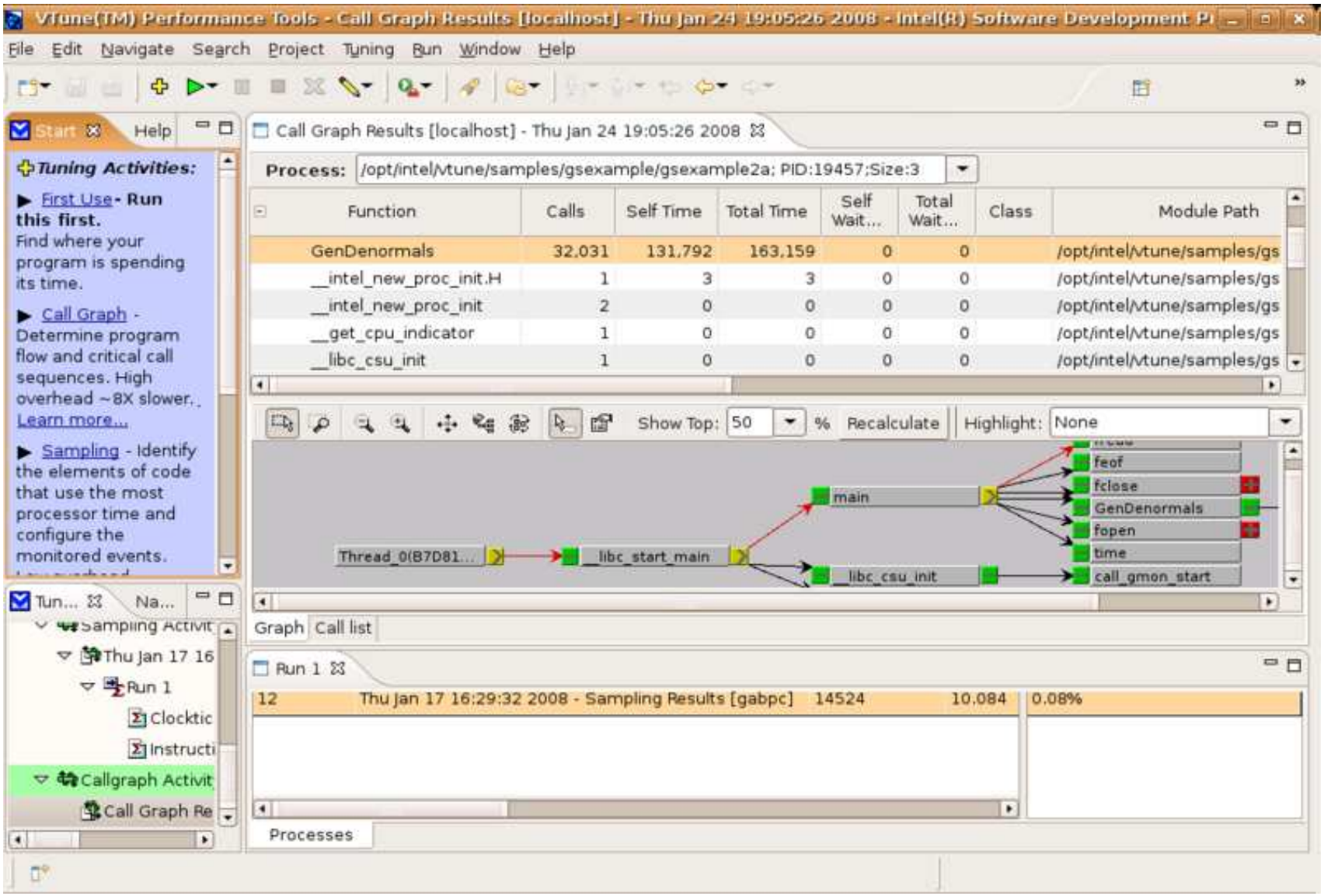
LTTV Screenshot



Intel VTune Performance Analyzer

- A profiler tool for applications running on intel-based systems
- Collects information through sampling and profiling
  - Sampling is accomplished by interrupting the processor at regular intervals and collecting samples of instruction addresses
- Provides a number of views like process view, thread view, module view, function view, view by call site and the critical path view

Intel VTune Performance Analyzer (cont.)



Intel VTune (cont.)

- To deal with size explosion problem:
  - Sampling, both time-based sampling and event-based sampling
  - It provides a number of visualization techniques like scrolling, zooming, highlighting, and filtering (by process id, CPU number ..etc)

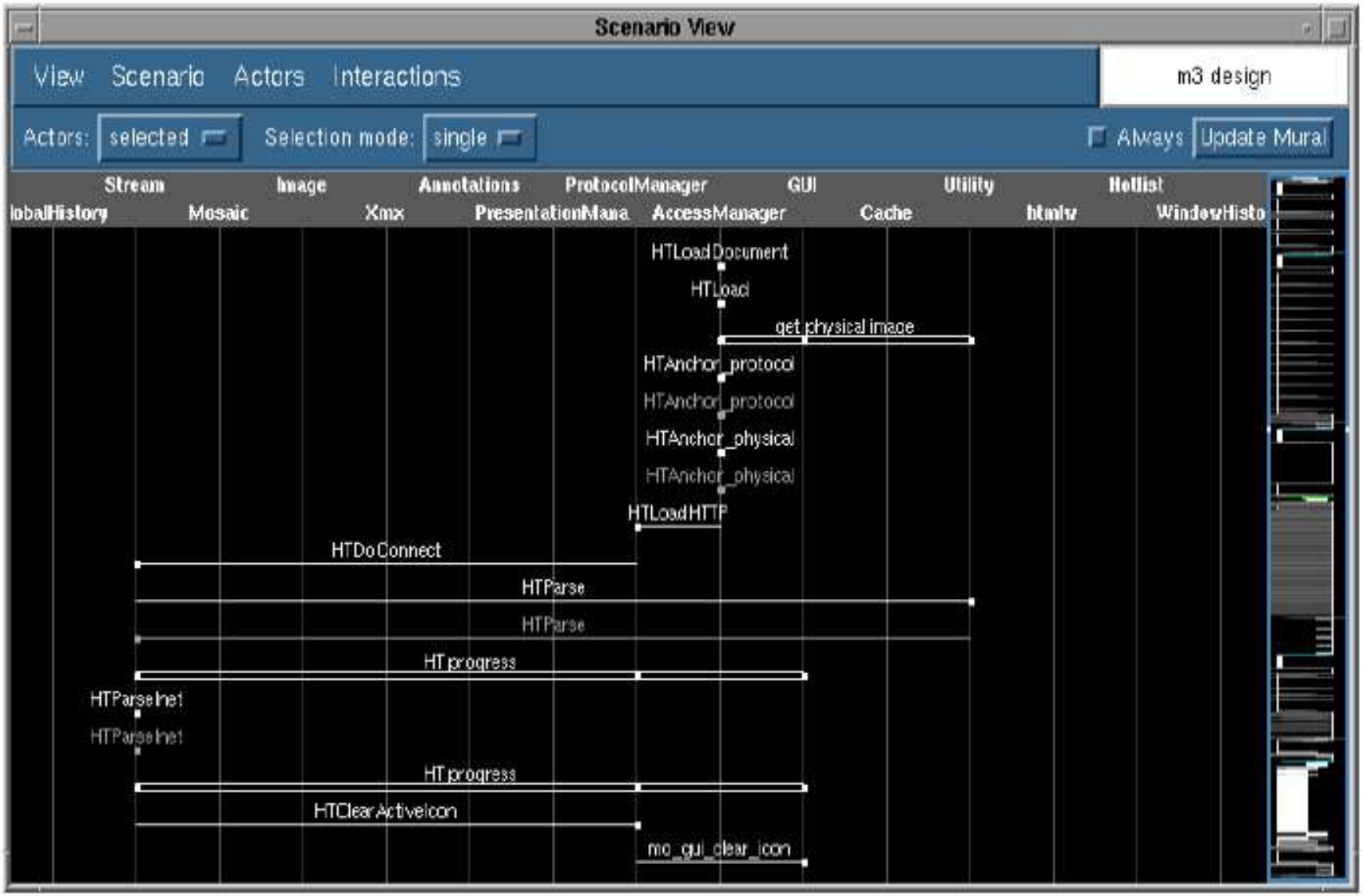
Wind River Workbench

- Wind River Linux uses the LTTng framework as a data provider
- Provides a set of tools and views for software development and debugging
- System Viewer displays the trace graphically in three different ways:
  - The Event Graph: Displays the succession of events relative to each thread
  - The Event Table: Displays events as rows of information ordered by their time stamp
  - The Memory usage graph displays memory allocation and deallocation

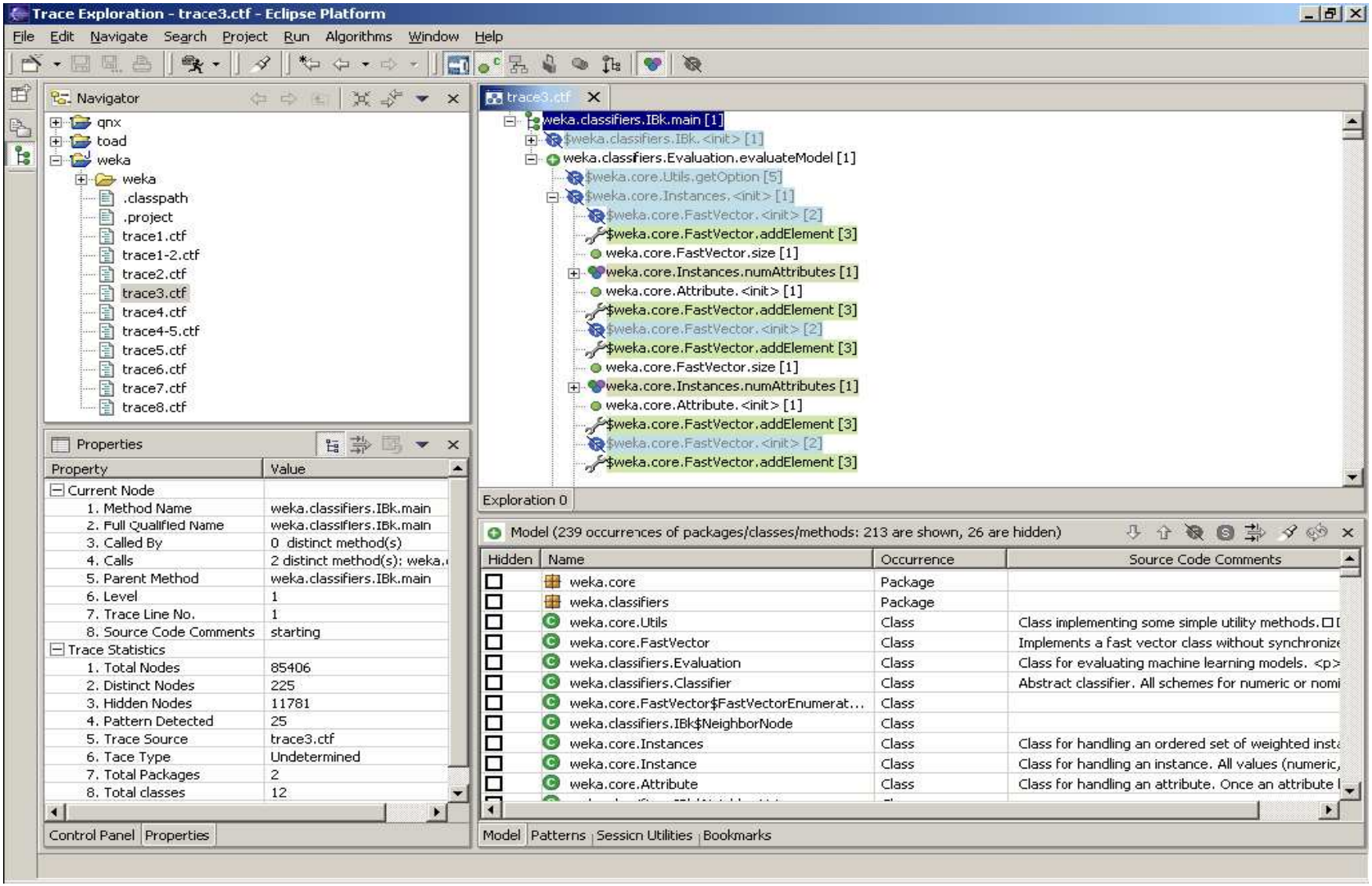
Wind River Workbench (cont.)

- To deal with size explosion problem:
  - Custom filtering is provided
  - Highlighting and selection
  - Multiple linked views
  - User-guided filtering

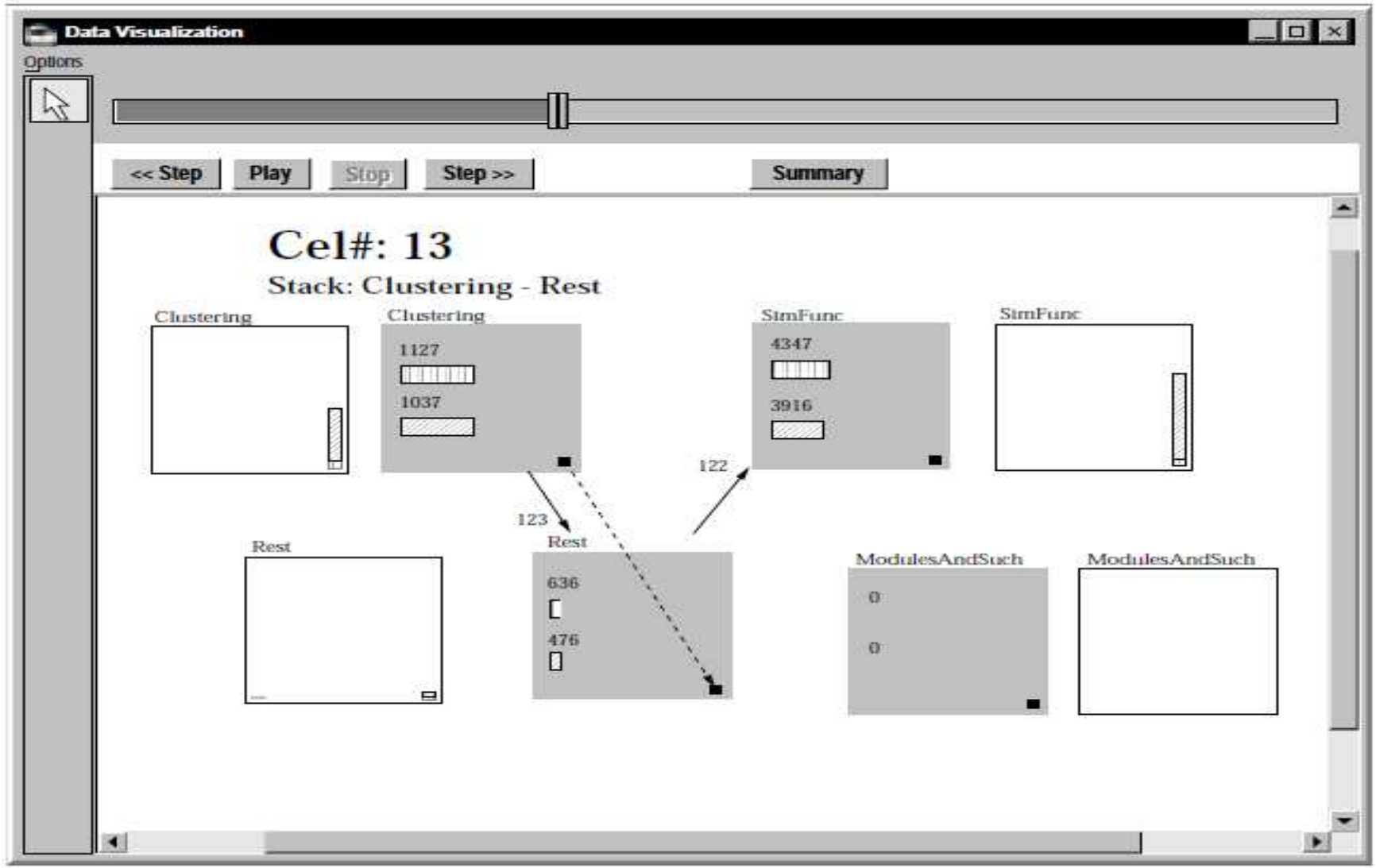
ISVis (Jerding et al. 97)



SEAT: Software Exploration and Analysis Tool (Hamou-Lhadj and Lethbridge)



AVID: Architecture Visualization of Dynamics in Systems (Walker et al. 2000)



Limitations of Existing Work

- Require extensive user involvement
- Description of high-level concepts is provided by the users
- Many don't scale up
- Some of them are not applicable to low-level traces such as system call traces
- Require fine tuning of parameters and thresholds (yet to be determined)

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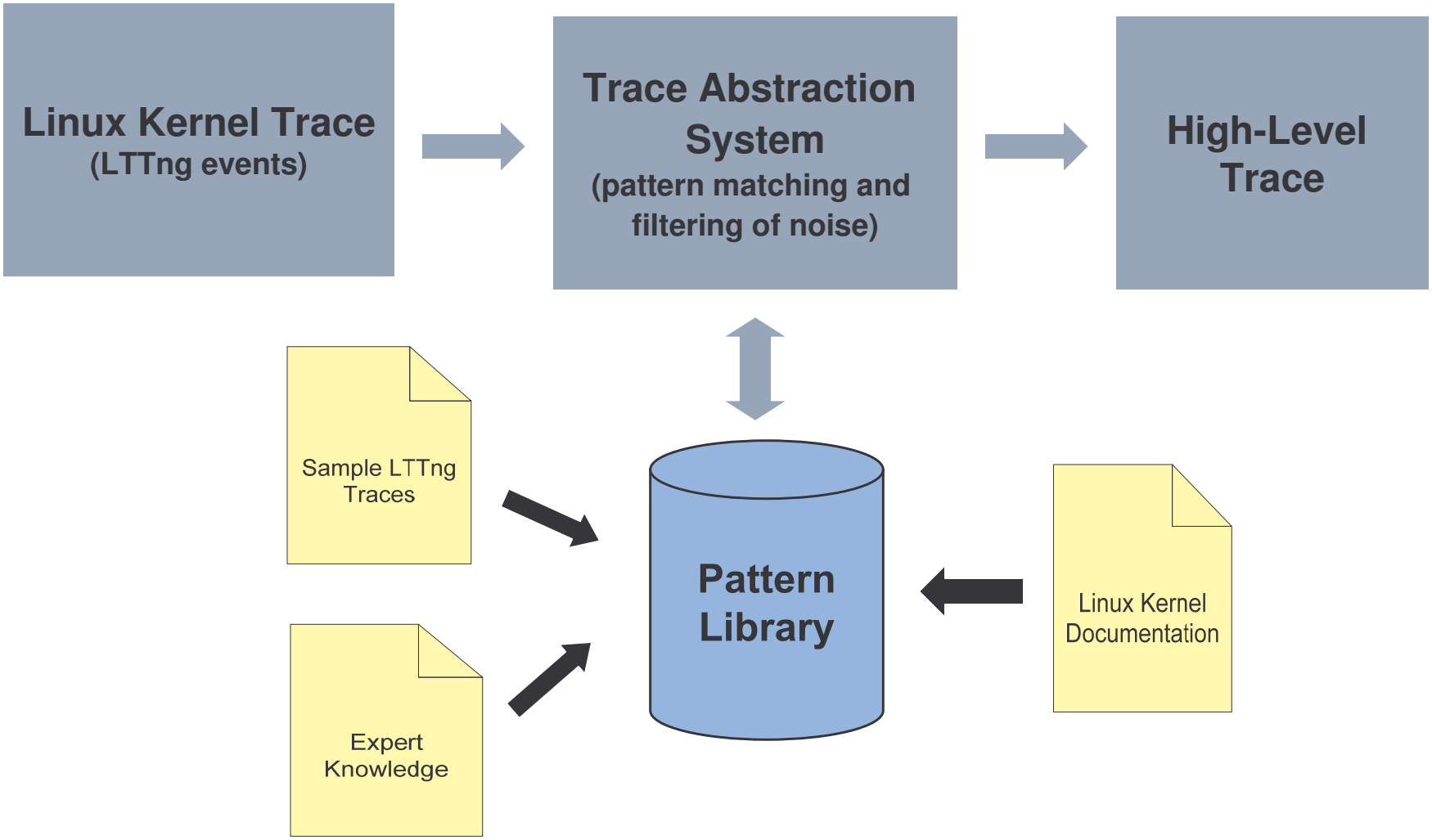
Approach for Abstracting LTTng Traces



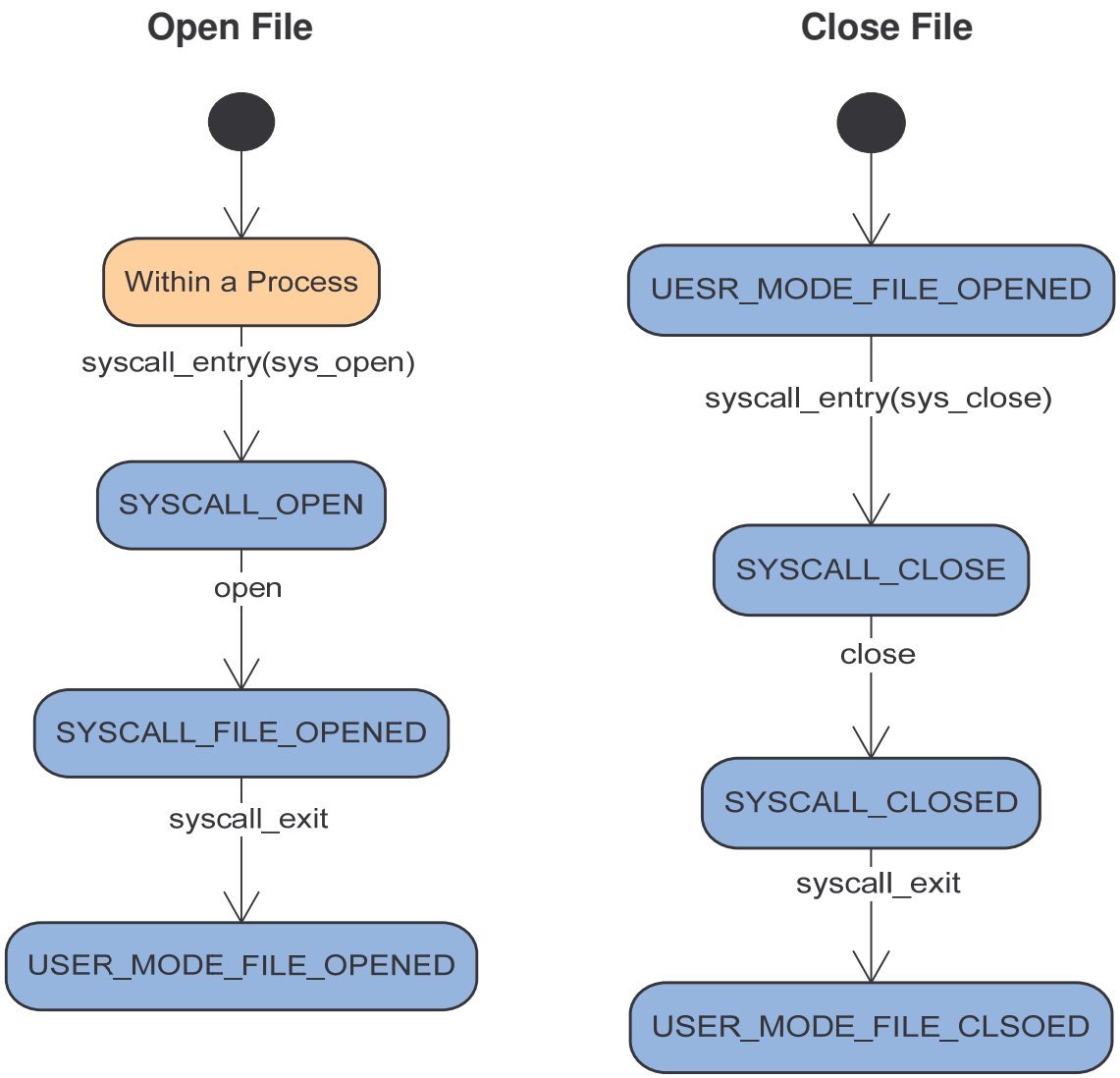
Pattern Library

- We have built a pattern library that contains patterns that represent key Linux kernel operations
  - File, socket and process management operations
- The patterns are modeled as UML state diagrams:
  - States represent system modes (user_mode, sys_call mode, etc.)
  - Events consist of LTTng events

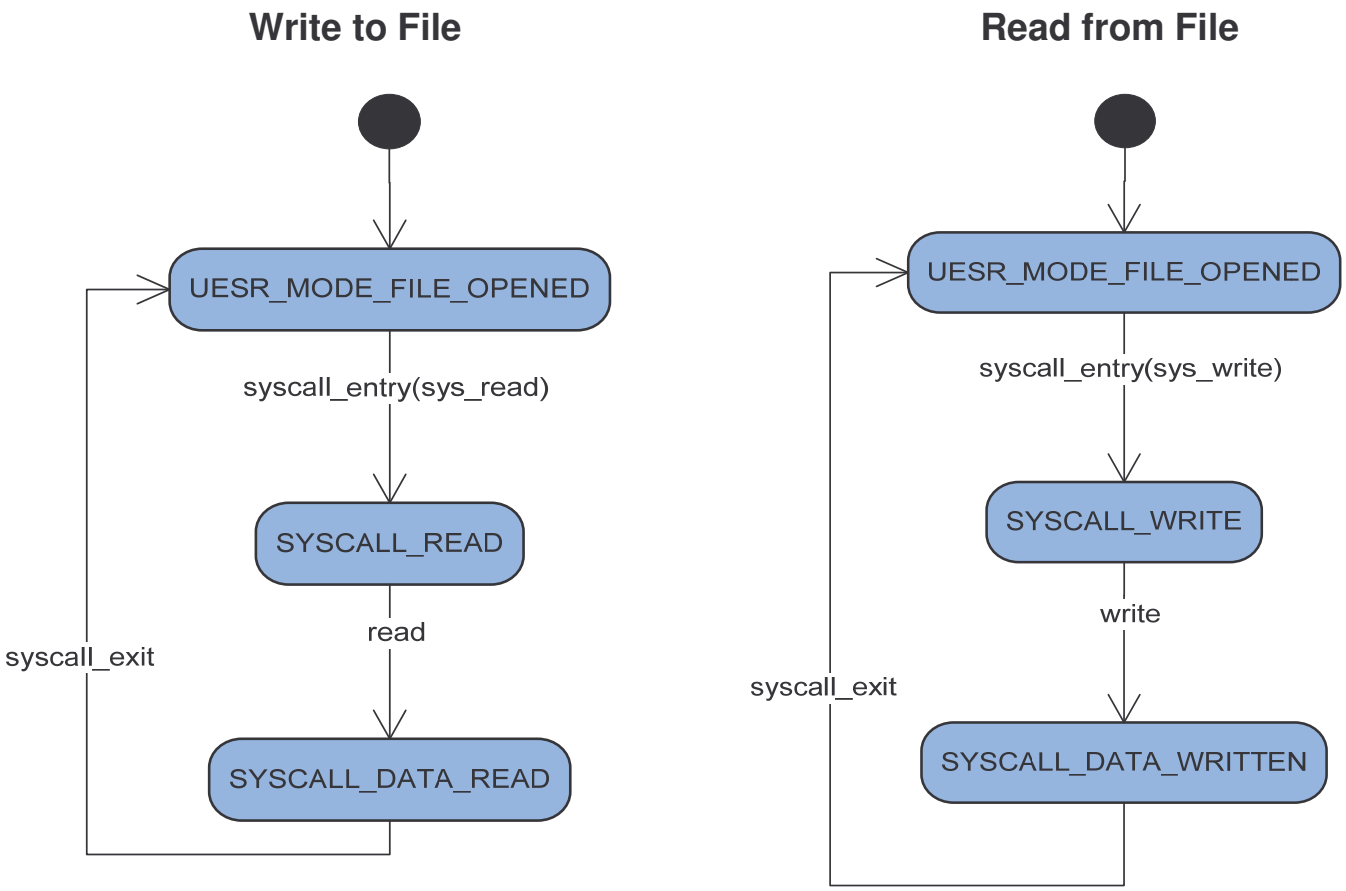
Patterns we have so far

- We created patterns for the following operations:
  - File Management (Open, Read, Write, Seek, Close)
  - Socket Management for both TCP and UDP (Create, Connect, Bind, Listen, Accept, Send, Receive, Close)
  - Process Management (Execution with exec and execve, Exit, Fork, Clone)

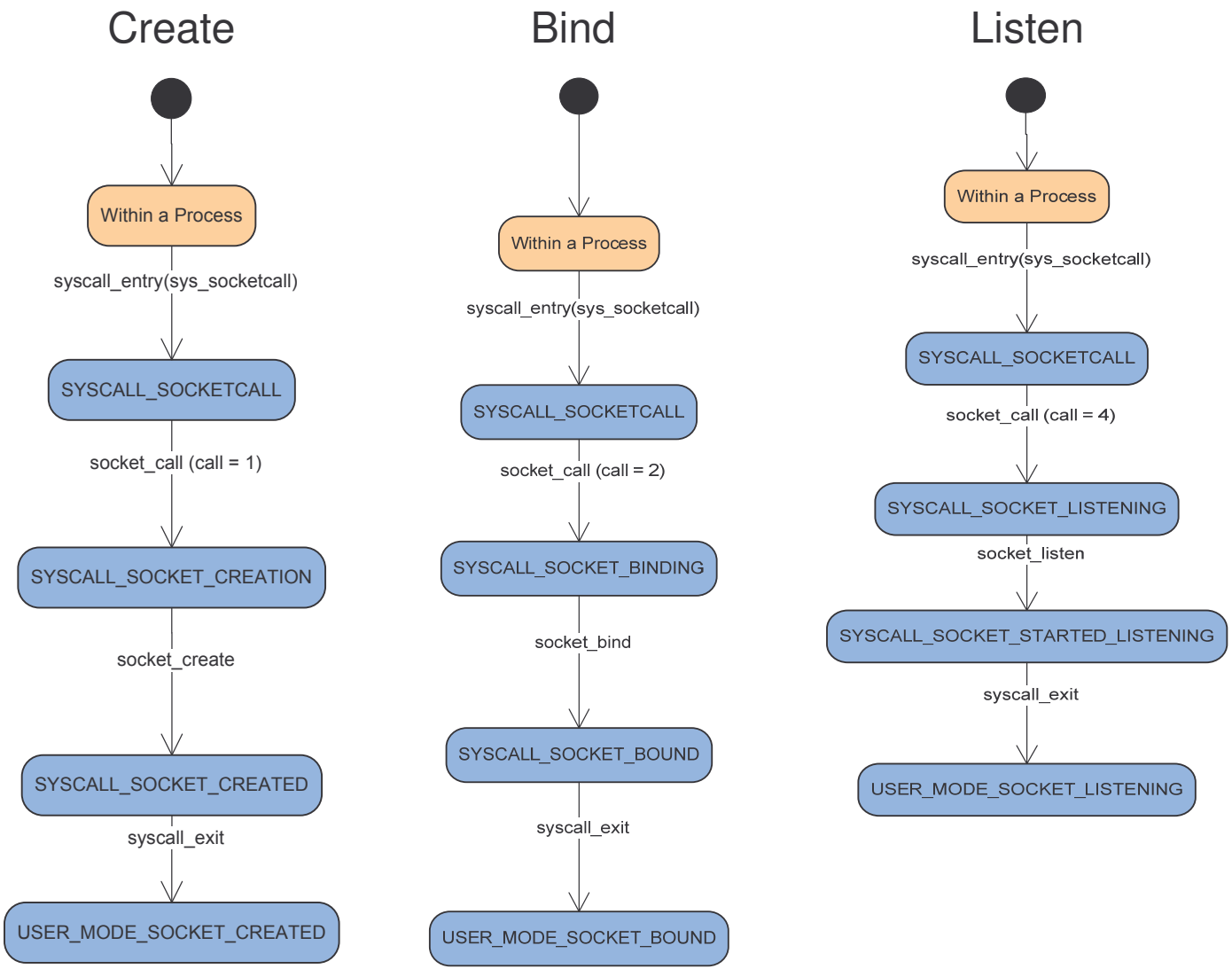
File Management: Open & Close



File Management: Read and Write

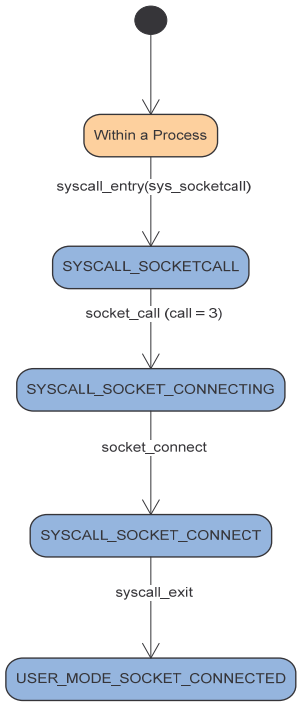


Socket Management (1)

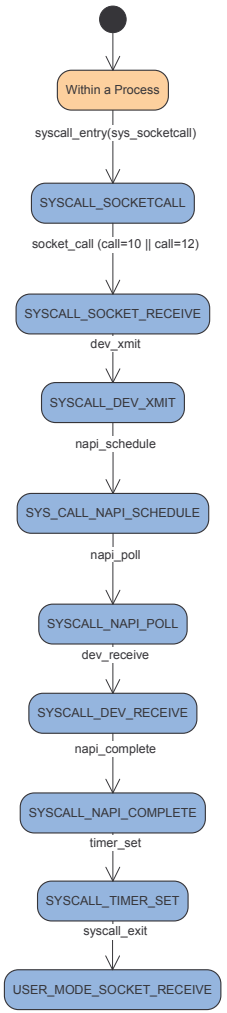


Socket Management (2)

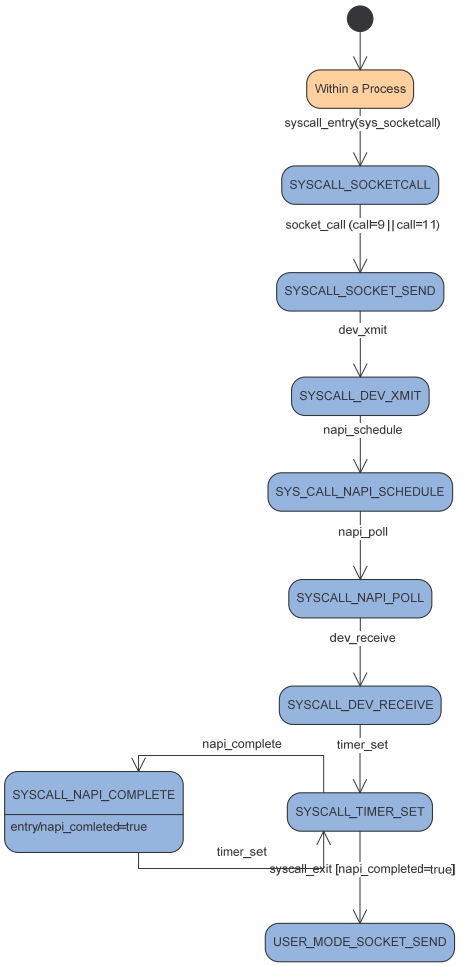
Connect



Receive

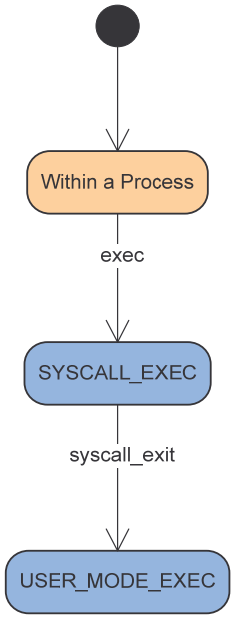


Send

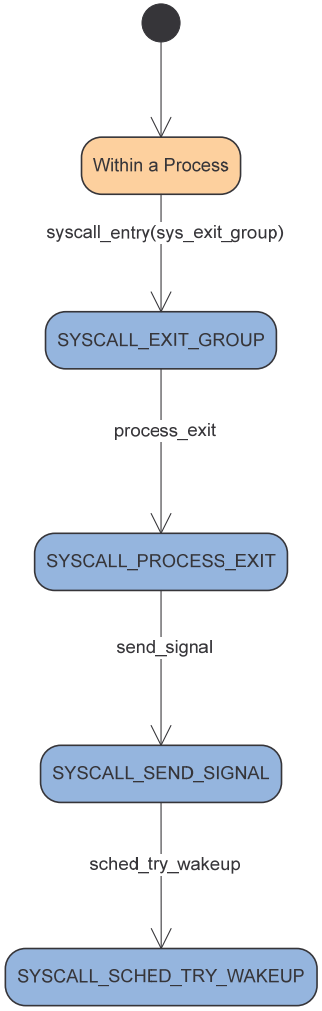


Process Management

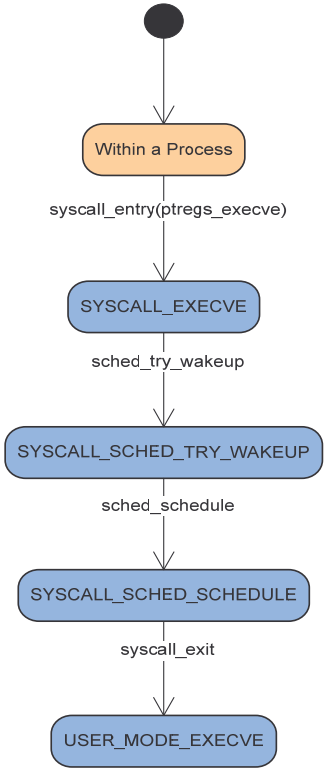
Execution with exec



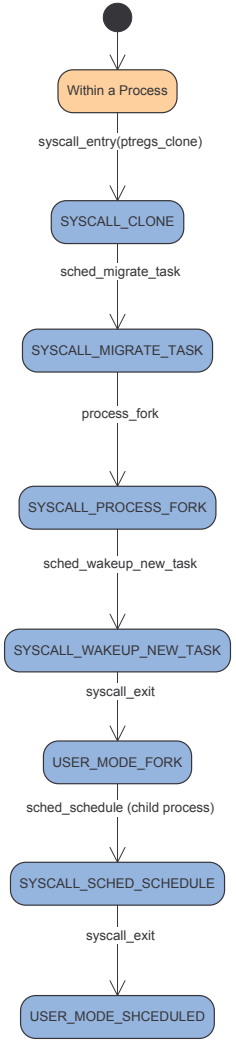
with execve



Exit



Cloning



Filtering of Noise

- We define noise in an LTTng trace as any event associated with memory management, page faults, and interrupts
  - can occur anywhere in the trace and in any order
  - are treated similarly to the way utilities have been treated in related work
- Associated events are treated as a set
  - i.e. order of occurrence of detailed events is ignored

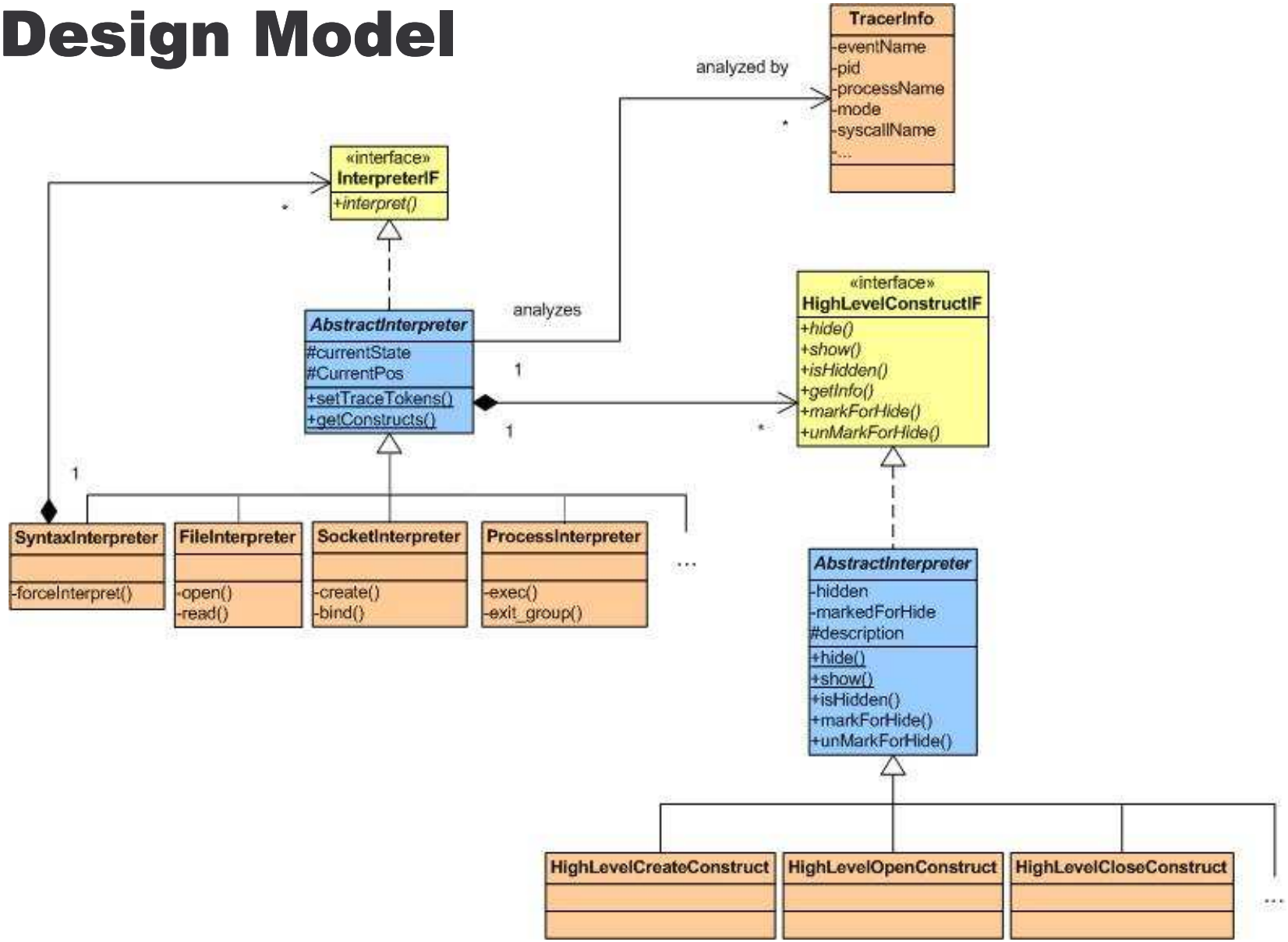
Validation of the Patterns

- We worked Pierre-Marc Fournier and Mathieu Desnoyers from École Polytechnique de Montréal to validate the patterns
  - Regular meetings with them have also helped in the process of understanding the markers used by LTTng
- Both users agreed with the way we defined noise found in traces
  - But further and more formal validation is needed

LTTng Trace Abstraction Tool

- We have built a prototype tool that takes an LTTng trace as inputs and return a more abstract trace by replacing
- Key characteristics of the tool:
  - Adding new patterns can easily be done
  - Multiple implementations representing different trace formats can be applied using the same interfaces
  - Noise interpreters are marked with the NoiseIF interface
  - High-level constructs can be hidden or shown easily by marking-unmarking them

Design Model



Some Preliminary Experiments

- We generated LTTng traces from small programs
  - Generated traces for the targeted processes contain around 1000 events
  - We were able to reduce the size of these traces to around 35 events
- We need to work on experimenting with larger traces (hundred of thousands of events)
  - From industrial systems with multiple processes

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Conclusion

- Trace abstraction is needed to make use of traces in an effective manner
- There are several techniques that have been proposed:
  - Pattern detection, filtering of noise, sampling, visualization
- We proposed a knowledge based approach to abstract out LTTng traces
  - A pattern library for main Linux Kernel operations has been created

Future Directions

- Continue developing and validating Linux sys calls patterns
- Start experimenting with large traces
- Completing
  - A paper that compares trace analysis tools
  - A paper on abstracting system call trace
    - The overall approach
    - The pattern library
    - Proof of concept

Thank You!
Questions and Discussion

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