Monitoring and Performance Analysis in Distributed Systems

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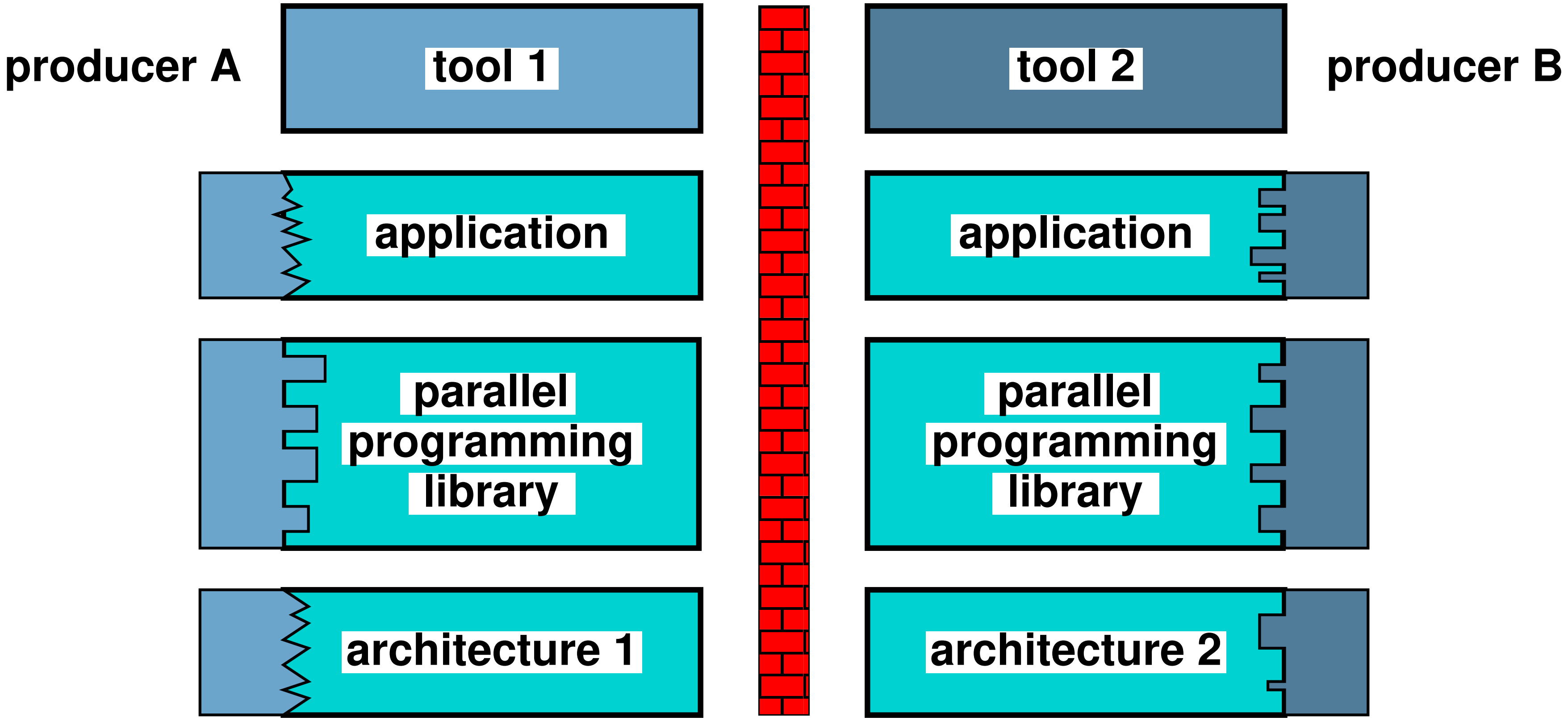
Agenda

- Monitoring of distributed systems
  - OMIS – On-line Monitoring Interface Specification
  - OCM – An Implementation of OMIS
- Distributed automatic performance analysis
  - Concepts from the APART working group
  - A possible implementation on the Grid

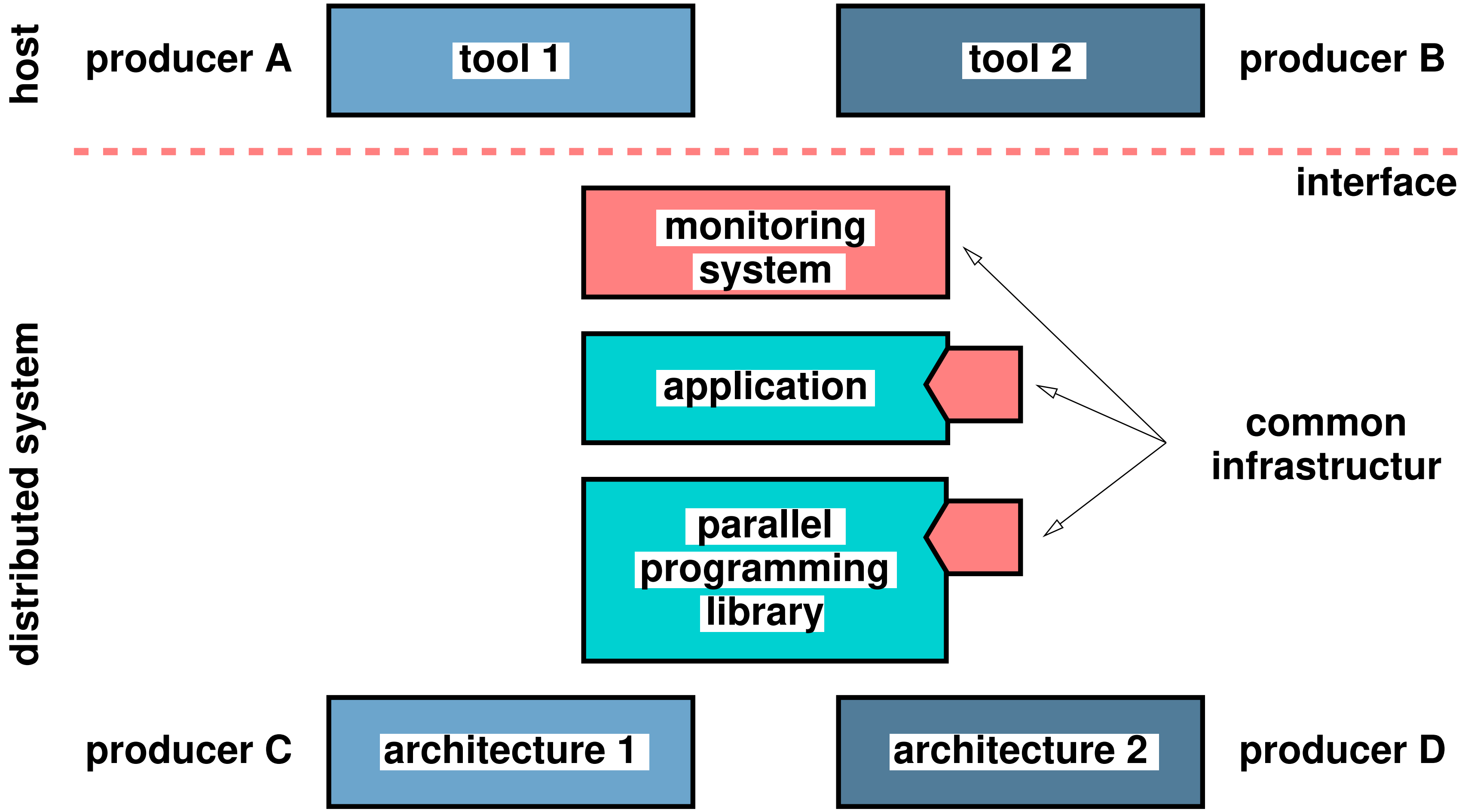
Motivation

- On-line tools need an infrastructure for **observation** and **manipulation** of program executions
  - e.g. debugging, performance analysis, load balancing, resource management, adaptive run-time systems, ...
- Currently:
  - proprietary monitoring systems
  - no standard infrastructure exists
- Consequences:
  - new tool $\Rightarrow$ new monitoring system
  - limited portability, no interoperation

Current Tool Design



Tool Design using OMIS



On-line Monitoring Interface Specification

The interface should ...

- support on-line monitoring
  - adjust at run-time what should be monitored
  - modify target's run-time behavior if desired
- be platform independent
  - platform $=$ hardware, operating system, progr. library
  - supports development of uniform tool environments
- be usable for any kind of run-time tool
  - observing and/or manipulating tools
  - interactive / automatic, centralized / distributed

On-line Monitoring Interface Specification

The interface should ...

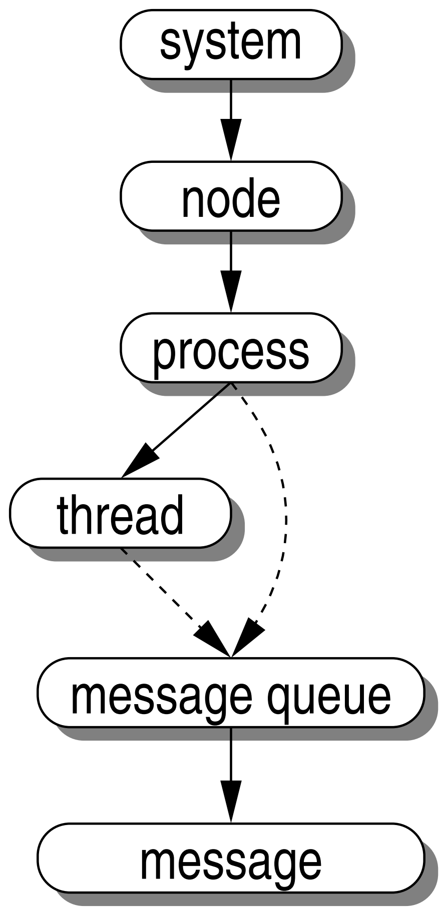
- support interoperable tools
  - sets of independent, small tools that can be used together
  - mechanisms for coordination between tools
- be efficient
  - minimal intrusion (CPU usage, communication)
  - scalability

☞ Meeting all of these requirements at the same time is hard

OMIS: Basic Concepts

Object based approach

- observed system is a hierarchical set of objects
  - classes: nodes, processes, threads, messages, and message queues
  - node/process model suitable for DMPs, NOWs, SMPs, and SMP clusters
- access via abstract identifiers (tokens)
- services observe and manipulate objects
  - OMIS core: platform independent serv.
  - others: platform specific extensions
- tools define their own view of the observed system



OMIS: Basic Concepts

Event / action paradigm

- monitoring requests consist of two parts
  - event definition specifies when something has to be done
  - action list specifies what has to be done
  - empty event definition $\Rightarrow$ execute action list immediately
  - ☞ tools differ mainly in the required event/action relations
  - ☞ events needed by different tools are fairly the same
  - ☞ actions may be more diverse $\Rightarrow$ extensions
- actions are autonomously executed by the monitoring system
  - ☞ monitoring system can be ‘programmed’ by a tool
- event context parameters: pass event information to actions

OMIS: Basic Concepts

Scalability

- services operate on sets of objects
- token expansion
  - object token $\Rightarrow$ set of all contained objects

Location transparency

- necessary for services on object sets
- token localization:
  - object token $\Rightarrow$ containing object

OMIS: Basic Concepts

Extensibility

- motivation:
  - tools may require special actions and/or events
  - execute parts of a tool in a distributed way
  - platform specific services and/or objects
- distributed tool extensions
  - independent of target system and OMIS implementation
  - OMIS defines both external and internal interface
- monitor extensions
  - may depend on target system and OMIS impl.
  - OMIS only defines the external interface

OMIS: Basic Concepts

OMIS Request Examples

```
thread_reached_addr([p_14,p_52], 0x1234):
     thread_stop([]) thread_get_backtrace($thread, 0)
```

- When (a thread in) one of the specified processes reaches the breakpoint, stop the whole application and return the stack backtrace

```
thread_has_started_lib_call([p_21], "pvm_send"):
     pa_counter_local_increment(pa_lc_1, $par5)
```

- When (a thread in) process p_21 starts a send call, add the message size (event context paramerter par5) to a counter

A More Complex Example

```
thread_has_ended_lib_call([a_], "pvm_recv") :
        pa_counter_global_increment(pa_c_1, 1)

thread_creates_proc([a_]) :
        node_attach([$new_node])
        proc_attach([$new_proc])

:   pa_counter_global_read([pa_c_1], 1)
```

➠ Count the total number of `pcm_recv` calls in all processes

A Still More Complex Example

```
:   pa_ac_create()

:   array_insert_index(p_1,pa_ac_1)

thread_has_ended_lib_call([a_], "pvm_recv") :
       pa_counter_local_increment(pa_ac_1<$proc>, 1)

thread_creates_proc([a_]) :
       node_attach([$new_node])
       proc_attach([$new_proc])
       aray_insert_index($new_proc, pa_ac_1)

:   pa_counter_local_read([pa_ac_1], 1)
```

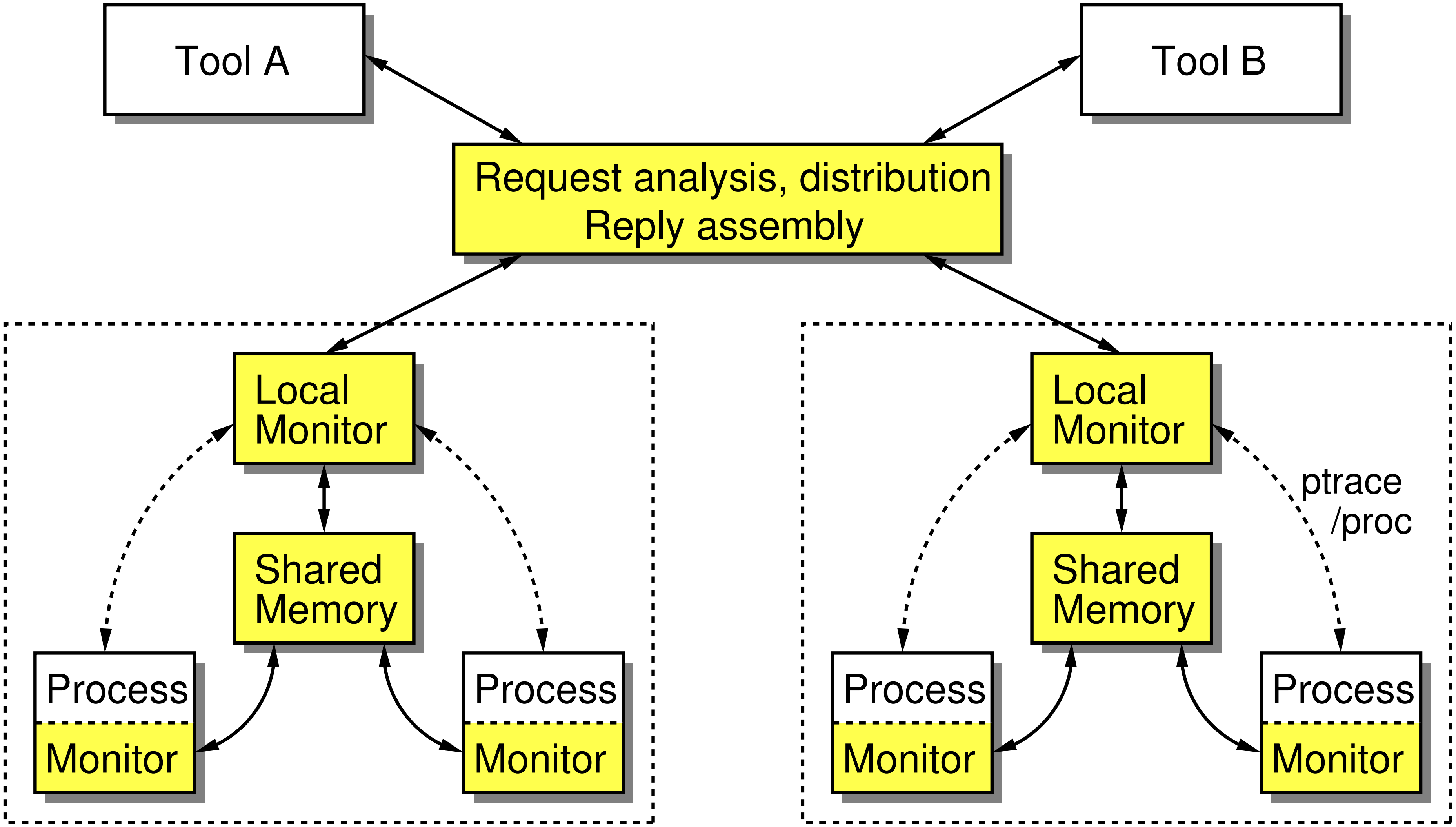
- Count the number of `pcm_recv` calls for each process

OCM – An Implementation of OMIS

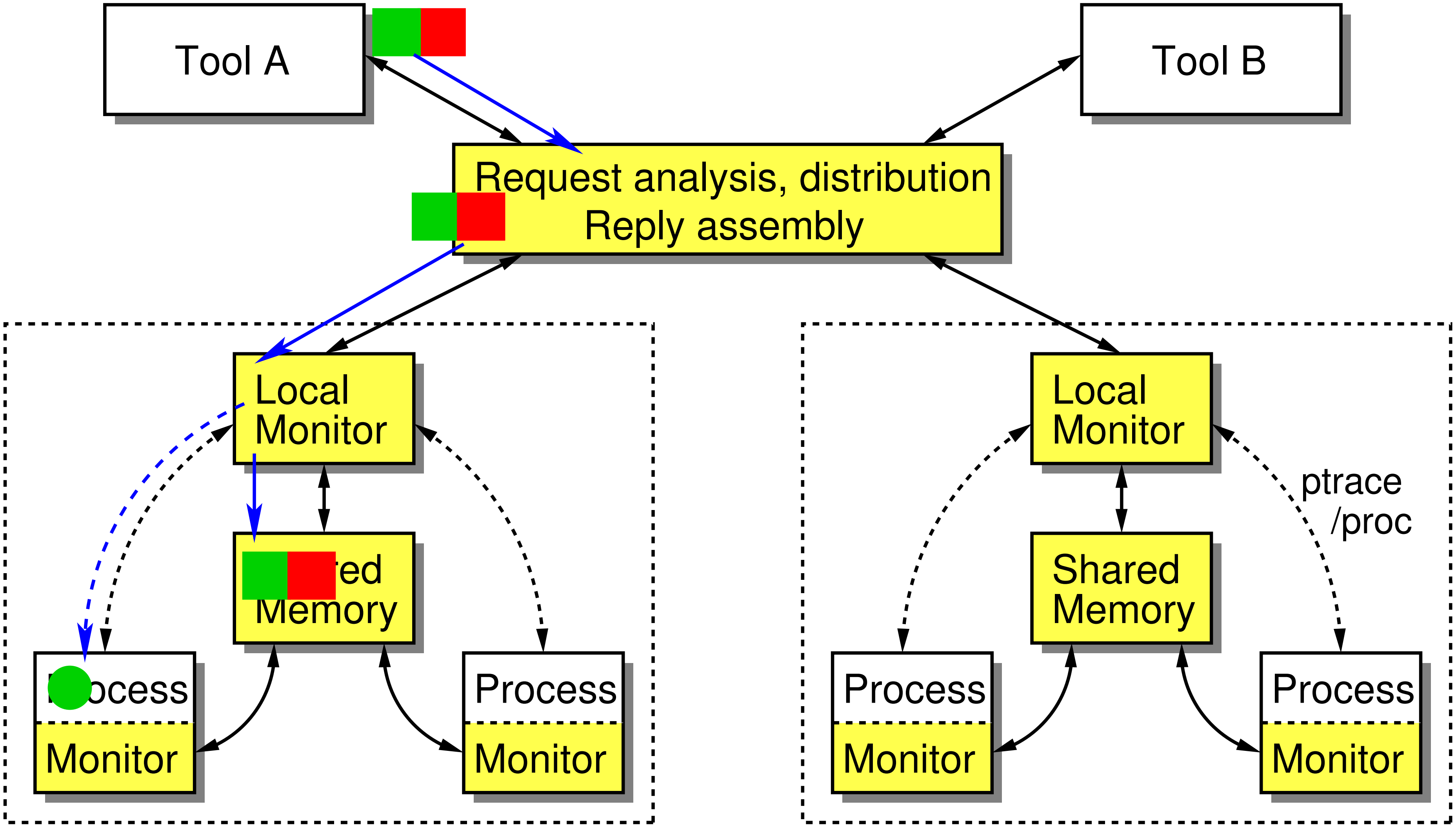
OCM = OMIS compliant monitoring system

- reference implementation of OMIS
- supports PVM and MPI on NOWs (Solaris, Irix, Linux, ...)
- first tools are available (debugger, visualizer, performance analyzer)
- ports to other platforms:
  - Java
  - Grid (see Marian Bubak's talk)
  - SCI-Cluster (SMiLE)

Structure of the OCM



Request Processing in the OCM



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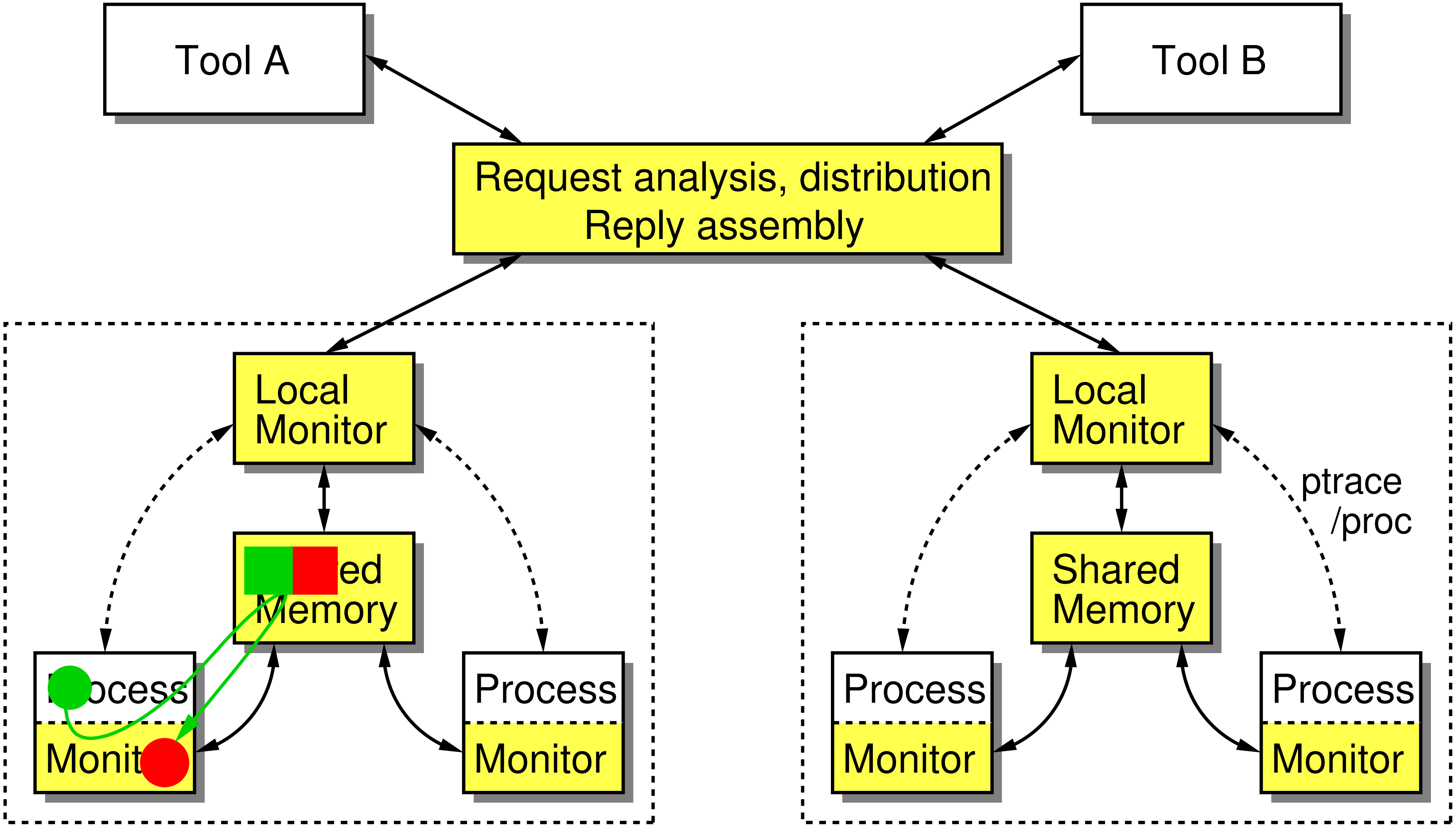

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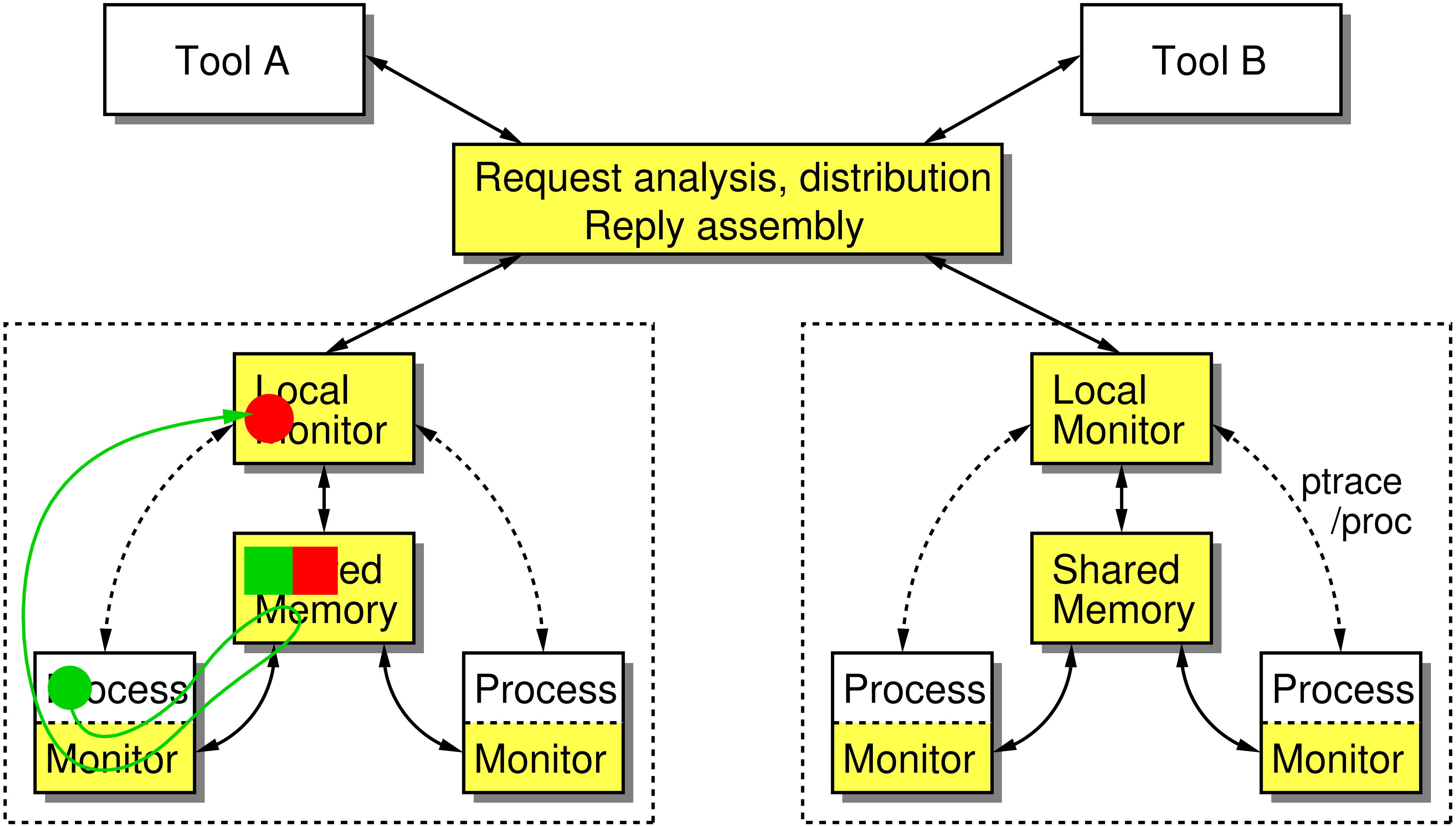
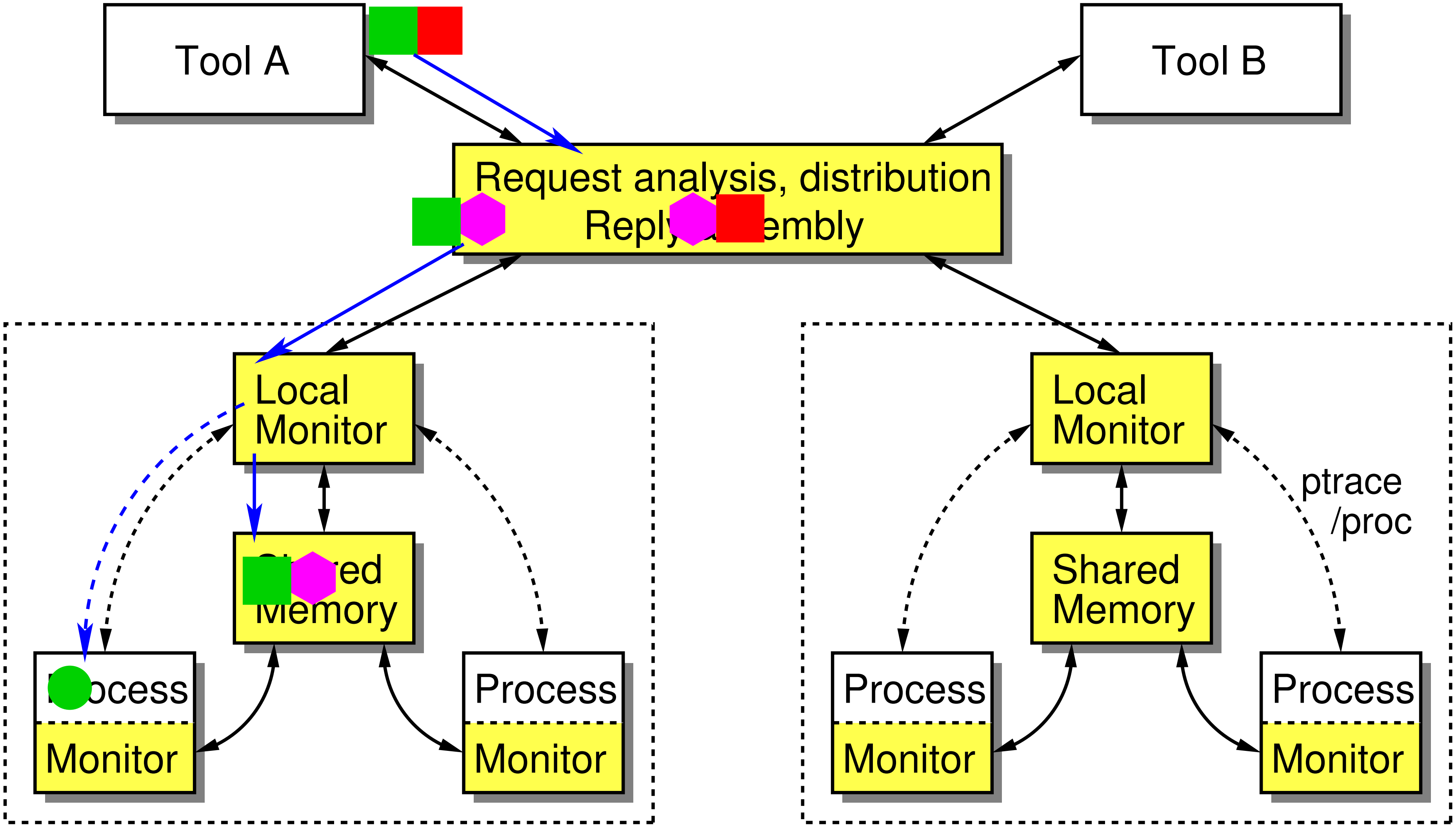
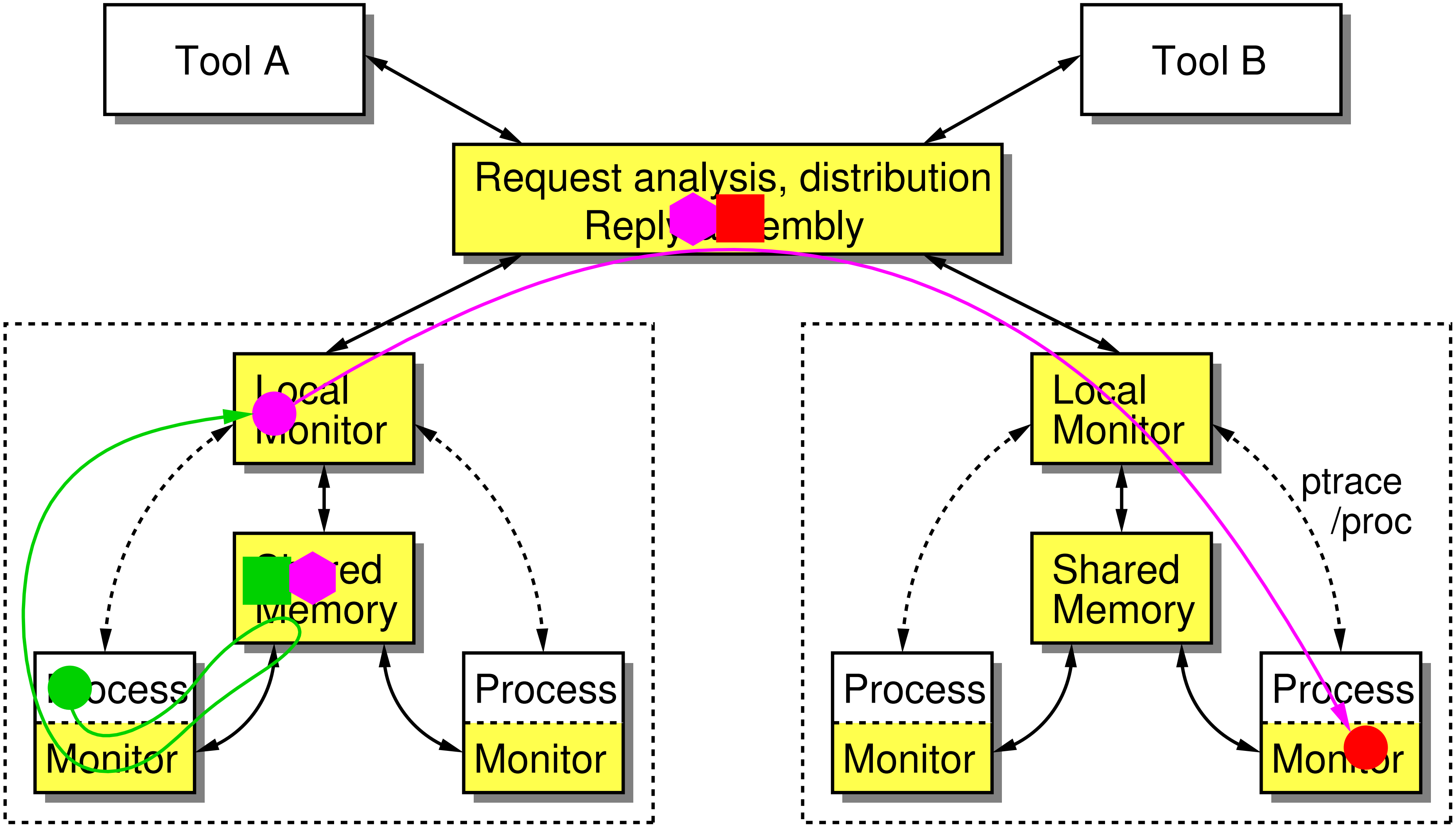


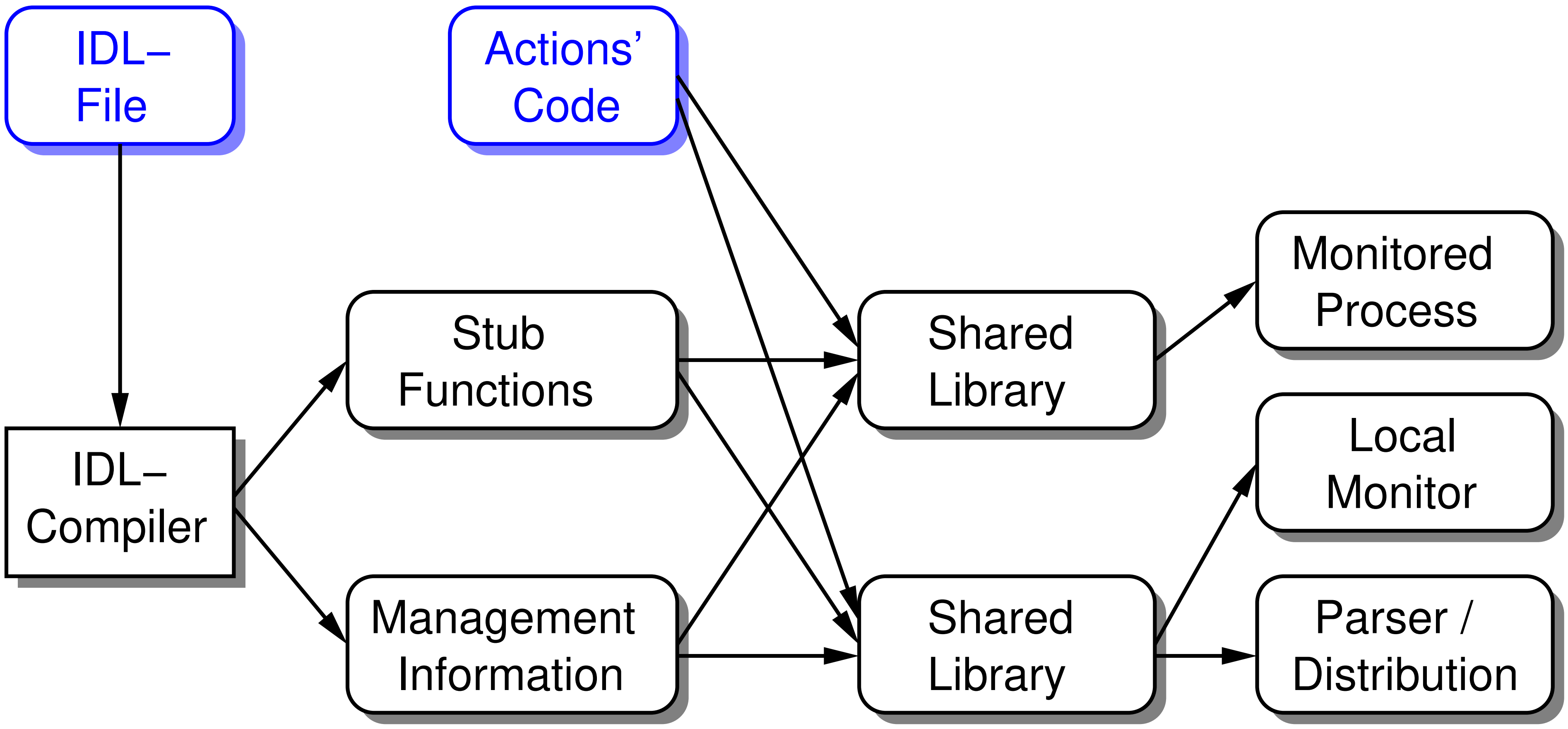
Request Processing in the OCM



Request Processing in the OCM



Extending the OCM: new Actions



OMIS/OCM for the Grid

Why OMIS/OCM for the Grid?

- on-line monitoring
  - optimization, resource management, steering
- uniform interface on all platforms
  - tools for heterogeneous systems
- distributed request processing
  - efficiency in distributed systems
- support for interoperability
  - collaborative use of tools ?

Why Automatic Performance Analysis for the Grid?

- user friendliness
- users do not have/need knowledge about execution platforms
- tracing and off-line analysis is prohibitively expensive
- programs can not be rerun in the same environment
  - no repeated tracing / profiling
- batch-oriented usage of the Grid
  - interactive tools are difficult to apply
- execution environment not known a-priori
  - no a-priori optimization
  - on-line tuning? (e.g. optimal number of workers)

Concepts from APART

The APART Working Group

- ESPRIT working group (1999-2000, 2001-2004)
- coordinates projects on automatic performance analysis:
  - Aurora (Univ. Vienna)
  - Peridot (Techn. Univ. Munich)
  - OVALTINE/ADAPT (Univ. Manchester)
  - KOJAK (FZJ)
  - Kappa-Pi (Univ. Autònoma de Barcelona)
  - [Paradyn (Univ. Madison)]

Concepts from APART

The APART Approach

- object oriented performance data model
  - available performance data
  - different kinds and sources, e.g. profiles, traces, ...
  - make use of existing monitoring tools
- formal specification of performance properties
  - possible bottlenecks in an application
  - specific to programming paradigm
  - APART specification language (ASL)
- (specification of analysis process)

Concepts from APART

Property Specification in ASL

```
PROPERTY TEMPLATE CostPerProcess <float CostFunc(MPISummary)>
    (Region r, Experiment e, Process p, Region RankBasis)
{
    LET  cost = CostFunc(summary(r,e,p))
    IN   CONDITION: cost > 0;
         CONFIDENCE: 1;
         SEVERITY: cost/duration(RankBasis,e);
}

float IoCostFunc(MPISummary rs) = rs.IoTime;
float CommCostFunc(MPISummary rs) = rs.CommTime;

PROPERTY CostPerProcess <IoCostFunc> IoCostPerProcess;
PROPERTY CostPerProcess <CommCostFunc> CommCostPerProcess;
```

Concepts from APART

Property Specification in ASL

```
PROPERTY TEMPLATE PropertyOnAllProcesses
    <PROPERTY x(Region, Experiment, Process, Region)>
    (Region r, Experiment e, Region RankBasis)
{
    CONDITION:  Forall p IN e.processors SUCH THAT
                   condition(x(r,e,p,RankBasis)) AND
                   confidence(x(r,e,p,RankBasis)) ==1;
    CONFIDENCE: 1;
    SEVERITY:   max(severity(x(r,e,p,RankBasis))
                    WHERE p in e.processes)
}

PROPERTY PropertyOnAllProcesses <IoCostPerProcess> IoCost;
PROPERTY PropertyOnAllProcesses <CommCostPerProcess> CommCost;
```

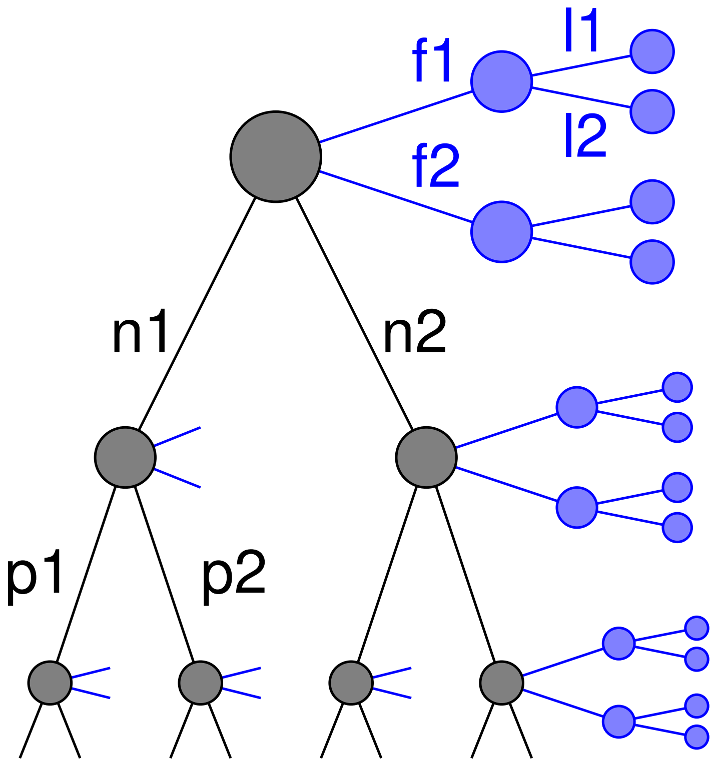
Concepts from APART

“Granularity” of Properties

- location
  - whole system, cluster, machine, process, thread
- program structure (region)
  - program, module, function, loop, basic block, statement
- time
  - complete execution, execution phases

$\Rightarrow$ **Multidimensional Tree of Properties**

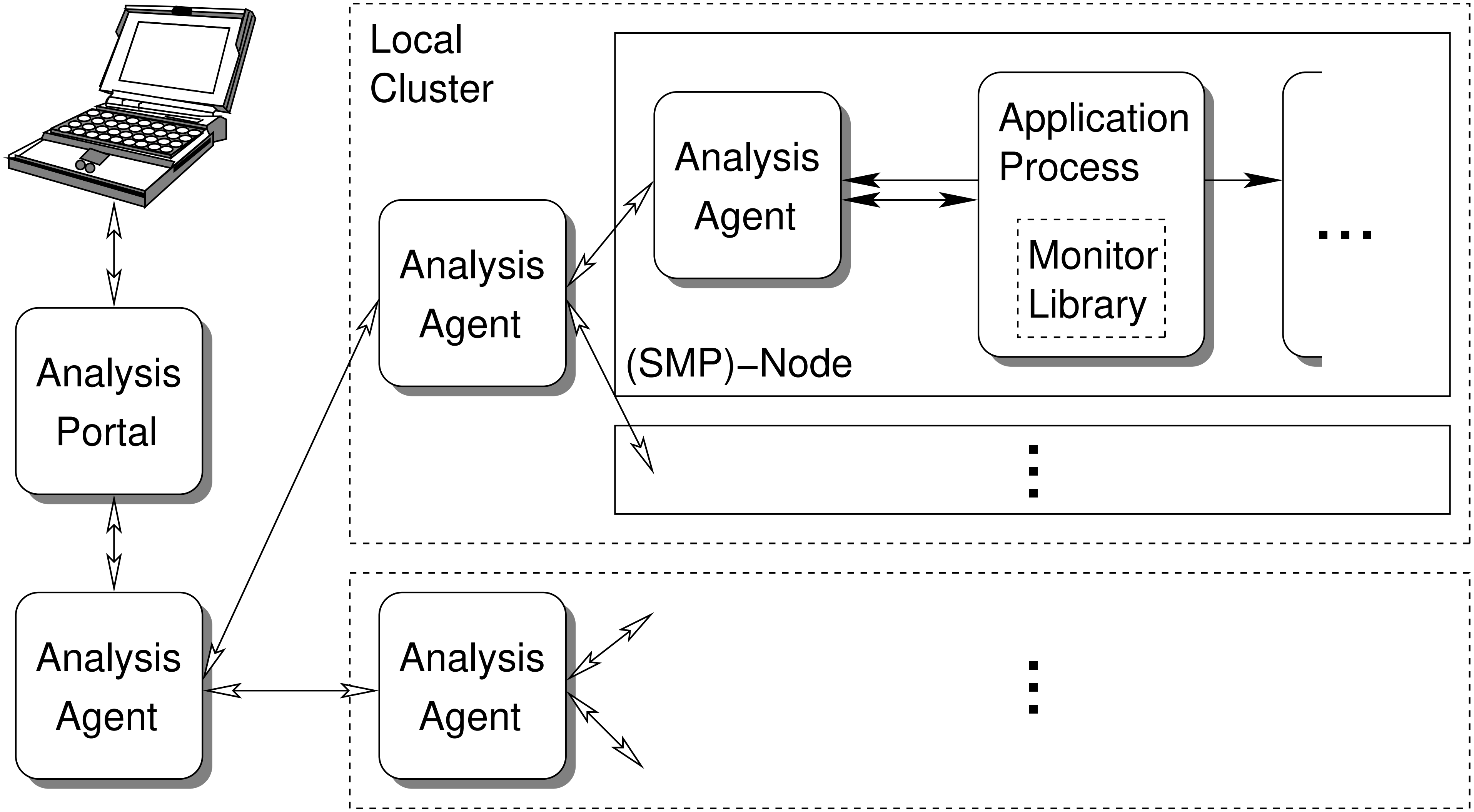
Tree of Properties



- search strategy?
  - top-down (hypothesis driven)
  - bottom-up (data driven)
- in addition to refinement
  - properties with "distributed" conditions
    e.g. load imbalance

A Possible Implementation on the Grid

Agent Hierarchy



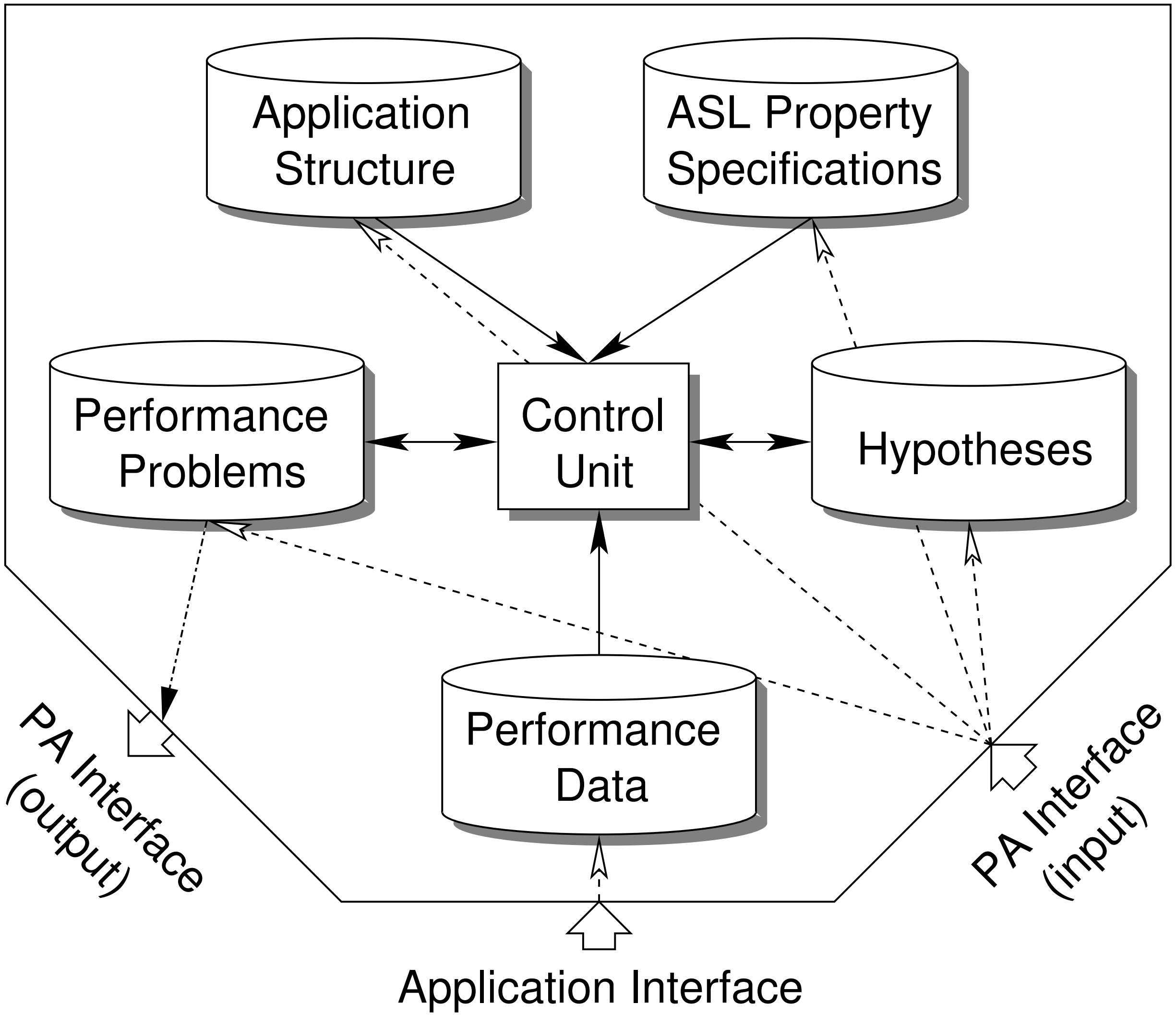
A Possible Implementation on the Grid

Communication

- towards leaves:
  - ASL property specifications
  - program structure information
  - evaluation requests for hypotheses
  - priorities for hypotheses
- towards root:
  - performance problems
  - partially evaluated hypotheses

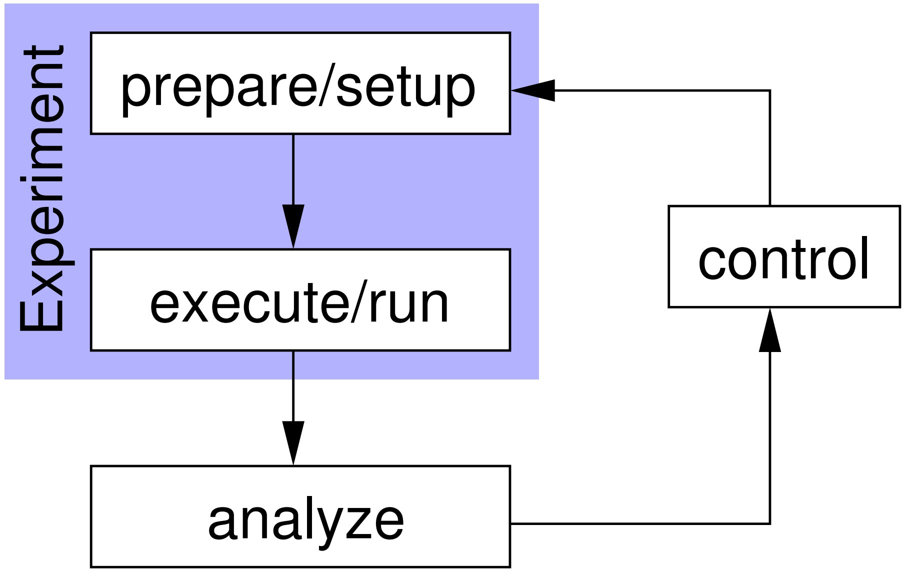
A Possible Implementation on the Grid

Structure of an Agent



A Possible Implementation on the Grid

Performance Experiments in APART



Types of experiments

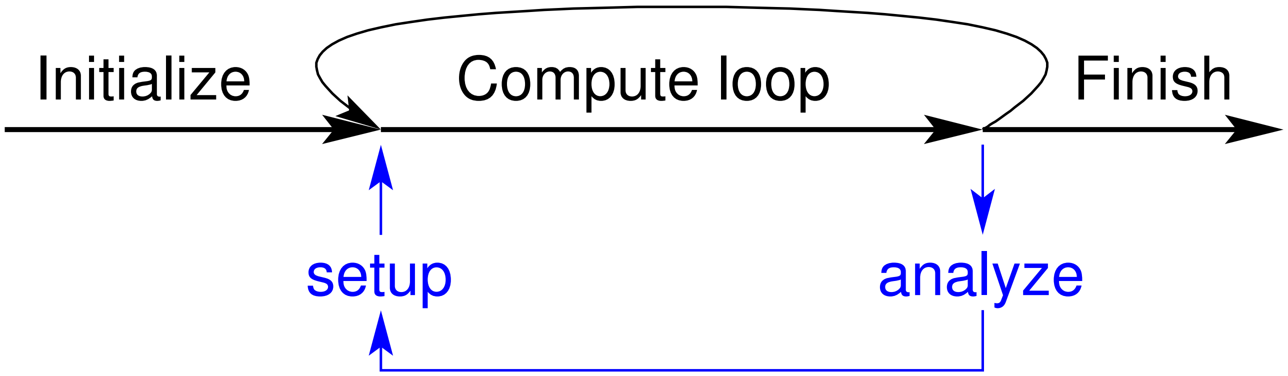
- multiple complete executions
  - e.g. for scalability analysis
- single complete execution
  - off-line monitoring
- part of an execution
  - on-line monitoring

For the Grid

- on-line monitoring (amount of data, repeatability)
- needs knowledge on execution phases

A Possible Implementation on the Grid

Execution Phases



- refinement of hypotheses only possible for repeating phases
- ideally: phases marked by programmer
- fallbacks:
  - loop information from compiler
  - extry / exit of “large” functions

A Possible Implementation on the Grid

Program Pattern Information

- optional information on application's design patterns
  - e.g. SPMD, master/worker, pipeline, divide & conquer, ...
- allows to derive more special performance properties, e.g.
  - *master is overloaded*
  - *pipeline stalled by stage xyz*
- incremental on-line specification of patterns
  - mapping to symbolic information compiled into executable
    e.g. line numbers, function names, ...

Status

Automatic Performance Analysis

- APART: ASL and principal design
- Peridot: design of on-line analysis agents
- ESPRIT proposal: extraction of high level performance properties on the Grid

OMIS/OCM

- OMIS 2.0 is available (`http://wwwbode.in.tum.de/~omis`)
- OCM will be released under GPL
- current work (ICS-AGH, Krakow):
  OCM for the Grid, Java-Extension for OMIS