Monitoring and Optimization of I/O performance with SIOX

Julian Kunkel[1] Michaela Zimmer[1] Marc Wiedemann[1]
Alvaro Aguilera[2] Holger Mickler[2]
Xuan Wang[3] Andriy Chut[3] Thomas Bönisch[3]
Jakob Lüttgau[1] Roman Michel[1] Johann Weging[1] Daniela Koudela[2]

1 University of Hamburg
2 ZIH Dresden
3 HLRS Stuttgart

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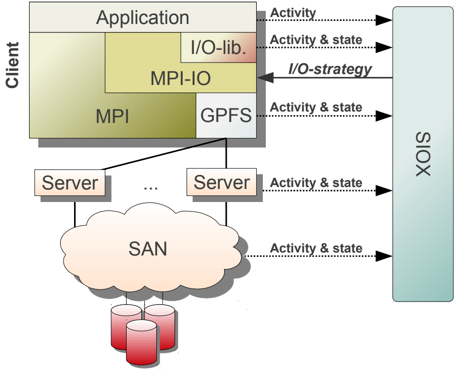
Project Goals



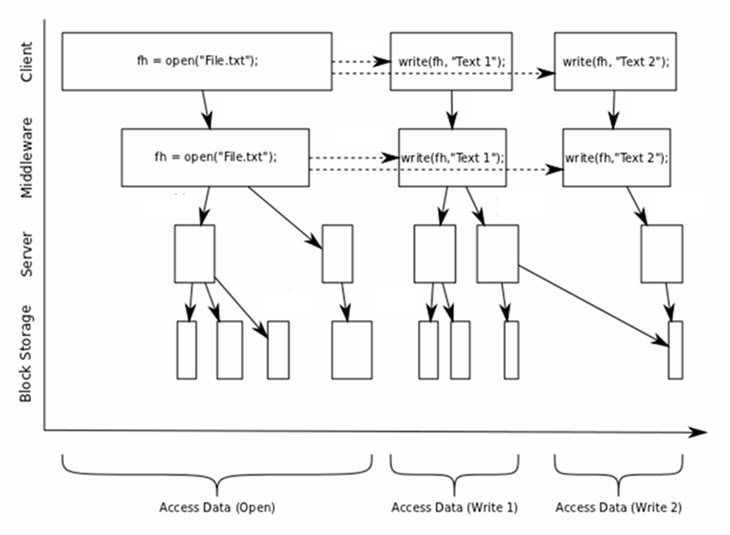
SIOX will

- collect and analyse
  - activity patterns and
  - performance metrics

in order to

- assess system performance
- locate and diagnose problem
- learn optimizations

Example Cause-and-Effect Chain



Partners and Funding

DKRZ
DEUTSCHES KLIMARECHENZENTRUM

Bundesministerium
für Bildung
und Forschung

H L R | S

IBM

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

- Funded by the BMBF
  Grant No.: 01 IH 11008 B
- Start: Juli 1st, 2011
- Duration: 36 Months

ZIH
Zentrum für Informationsdienste
und Hochleistungsrechnen

SIOX

Increasing SIOX's Capabilites

The project proposal targets instrumentation of

Selected applications, MPI-IO, POSIX and GPFS.

We designed a flexible modular architecture and API.

This allows us to integrate arbitrary:

- Libraries
- File systems
- Hardware information and statistics

An individual instantiation of modules is also possible:

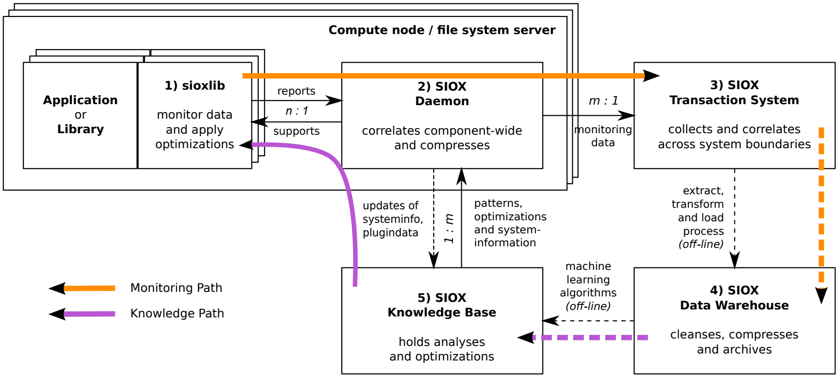
- Decide which modules are configured:
  - For each layer, process, compute and server nodes
- Each module has an XML configuration

Industry Collaboration

- We collaborate to develop industry-relevant software
  - Collaborating companies: Xyratex, Netapp
- We aim to deliver components to the Exascale10 (EIOW) middleware
  - Monitoring, machine learning, automatic optimization

- SIOX is licensed under LGPL3

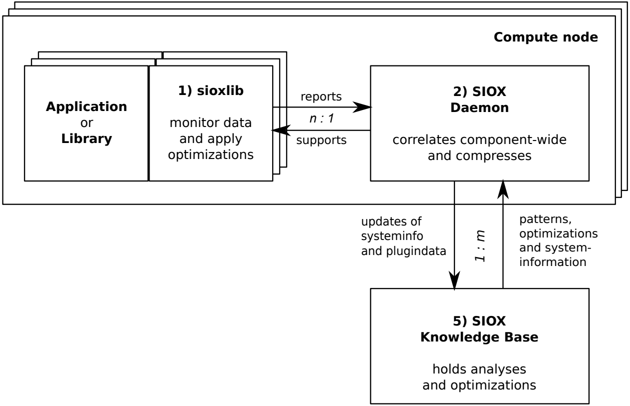
Faces of SIOX (1): General System Architecture



- Data gathered is stored via the *monitoring path*.
- Components receive the knowledge gleaned via the *knowledge path*.

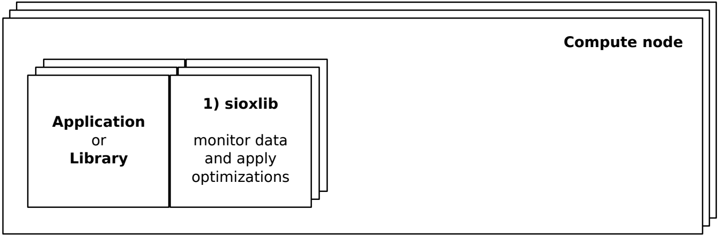
Faces of SIOX (2): Configuration for Online Mode

No pattern recording, optimization without machine learning



Faces of SIOX (3): Configuration for Static Knowledge

Apply static best-practices with low overhead



Overview of Concepts and Mechanisms

- User-level monitoring API
  - "Wrapper" to ease instrumentation of software layers
- Relation of activities
  - Implicit linking of process-internal activities
  - Explicit linking to remote activities
  - Explicit links are created during the ETL into the warehouse
- Analysis of observed activities and statistics by plug-ins
  - Synchronous and/or asynchronous
  - Activities can be handled stateful (within a process) or stateless
  - May use (static) system information/knowledge
- Incorporation of system knowledge
  - One database entry per node, file system, storage device
  - Plugins may create their own node/fs/device specific entries
  - Detect hardware changes (upon startup)
- Local and global "reasoning" to assess system state

Semi-Automatic Instrumentation of Software-Layers

Workflow

1. Save relevant function prototypes in a header file
2. Annotate functions in the header
3. Tool parses header and creates either
   - a shared library for `LD_PRELOAD`
   - a library to use with `ld --wrap`

Instrumentation can be done incrementally

Example Header for POSIX

```
//@component "POSIX"

//@register_metric fileName "File Name"
    ↪ SIOX_STORAGE_STRING
/////// END GLOBAL SECTION ////////////////

//@activity
//@activity_attribute fileName pathname
//@horizontal_map_put_int ret
//@error ''ret < 0'' errno
int open(const char *pathname, int flags, mode_t mode);

//@activity
//@activity_attribute bytesToWrite count
//@activity_link_int fd
//@error ''ret < 0'' errno
ssize_t write(int fd, const void *buf, size_t count);
```

Putting the Knowledge to Good Use

SIOX will exploit the knowledge gleaned to

- control available I/O optimizations

Internally, we will use it to

- adapt own level of activity to the host system's state
- reduce the amount of data logged
- focus and guide its acquisition of new data (active learning)

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Why can't we capture all events?

The Data Deluge – A Numerical Example

Assume program writes a 1 GB file to a parallel file system. . .

- . . . of 100 I/O servers managing 5,000 storage devices
- ⇒ 200 KB per device to write. . .
- . . . writing 4 KB per block on device
- ⇒ 250,000 blocks to write. . .
- . . . logging 20 B per block written
- ⇒ 5 MB logging data
- ⇒ *0.5 % logging overhead.*

The Data Deluge – A Numerical Example, Continued

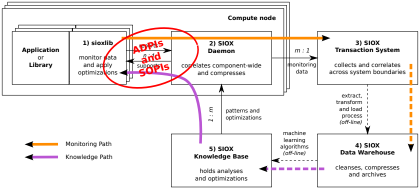
The HPC Cluster *Blizzard* at DKRZ reads and writes...

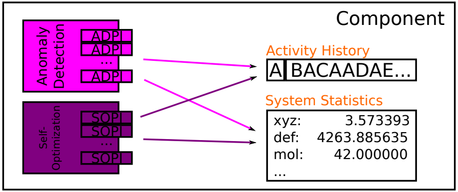
- ...10 GB/s, 24/7, 365 days a year
- $\Rightarrow$ 50 MB/s to log for SIOX
- $\Rightarrow$ 1.6 PB/a...
- ...at a very conservative estimate!

Intelligent Components

Each layer and daemon may use:

- Plug-ins to detect exceptional behavior and steer logging
- Plug-ins to suggest possible optimizations





Building SIOX's Brain

To harness the data gathered, SIOX uses *Knowledge Packages*.

A Knowledge Package. . .

consists of

- a Machine Learning Plug-In

and corresponding plugins

- Anomaly Detection Plug-In
- Self-Optimization Plug-In

Knowledge Package may use private *Action Tables* in the Knowledge Base.

The MLPI will create (and possibly update) the action table, which may also be done manually.

SOPI Example for `posix_fadvise()`

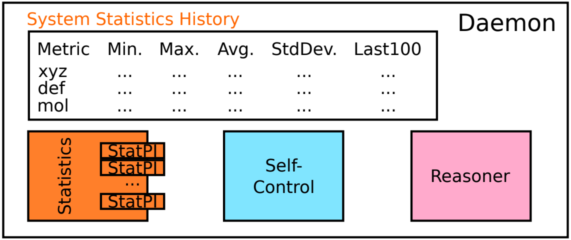
A more complex Action Table: Injecting non-functional calls

Action table

Pattern	Response
SequentialRead() SequentialRead() SequentialRead()	seq & willneed(size)
Open(ext = "nc")	willneed(0, 20 KiB)
Open(ext = "dat")	noReuse & random
RandomWrite(size < 4K){5x}	noReuse & random

A plug-in may use a state machine to track monitored activities

The SIOX Daemon

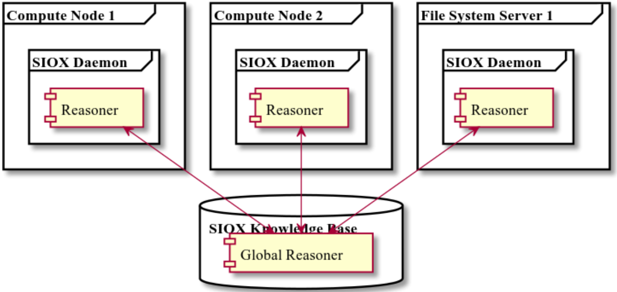


A physical node's daemon holds:

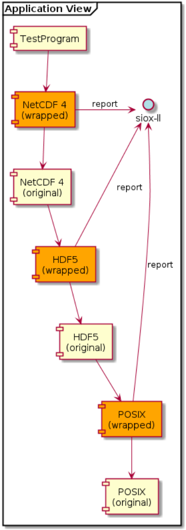
- Recent node-local system statistics, updated regularly
- A module with plug-ins to provide node-local system statistics
- A rule-based reasoner classifying system-state and bottlenecks
- A module with plug-ins to control SIOX's behavior

Reasoning

- Node-local reasoner decides when and how long to log
- System-state, detected bottlenecks and reasons are communicated
  - E.g. "Server overloaded", "Bad I/O pattern"
  - Refined knowledge is transferred to a global reasoner
  - Overview is communicated to all daemons
- Each reasoner maintains statistics for later investigation
- Feedback to user upon application termination



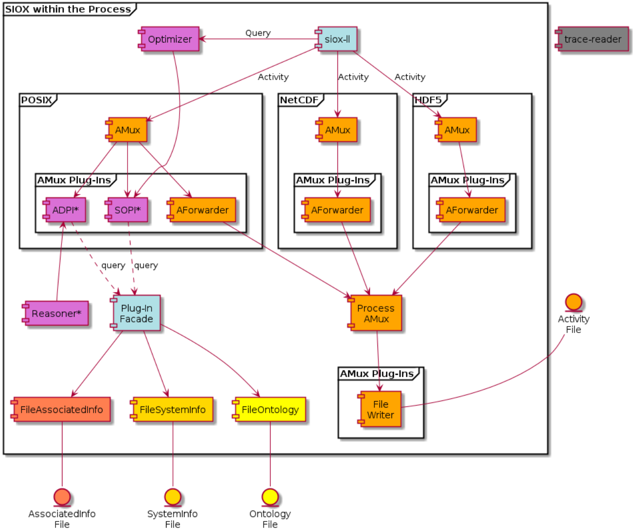
Currently Working Prototype



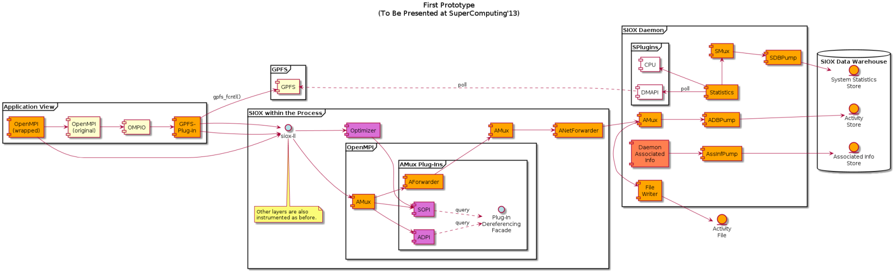
- SIOX manages data within a single process
- Full instrumentation for POSIX
- Partial instrumentations for NetCDF and HDF5

- Application behavior can be recorded in files
- Ontology and system information is stored in files
- Trace-reader parses all files

Currently Working Prototype – Internals



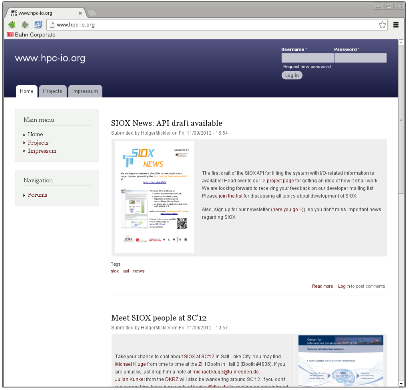
Towards a Prototype for SC'13



Summary

- SIOX aims to capture and optimize I/O
  - on all layers and filesystems
- Intelligent filtering reduces log size
- Integrated reasoning tries to localize causes and bottlenecks
- **We are building a flexible and open system**

Finally: SIOX and You



- Think we missed a problem?
- Think you could solve one?
- Like to see SIOX on your favourite file system?

We cordially invite you to become involved at

http://www.HPC-IO.org

Backupslides

SOPI Example 1

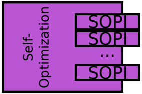
A simple Action Table: Adjusting a system parameter

Action table for an SOPI write-behind plug-in

Pattern	Buffer Size
Open()	4 MiB
Write(size $<$ 2 KiB){5x}	1 MiB
Write(size $<$ 4 MiB) Write(size $<$ 4 MiB)	20 MiB
Write(size $\geq$ 100 MiB)	direct-write

Self-Optimization Plug-Ins

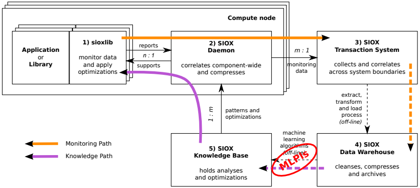
What SOPIs can do:



- Take any action available via any interface accessible, e.g.:
- Adjust system parameters (cache size, MPU size,. . .)
- Inject non-functional calls (`fadvise()`, MPI hints,. . .)
- Inject "housekeeping" calls (`flush()`, refresh page,. . .)
- Adjust parameters of functional calls (access mode, optional caching,. . .)
- Select between alternative modules to employ (MPICH2 vs. OpenMPI, shmem vs. TCP,. . .)

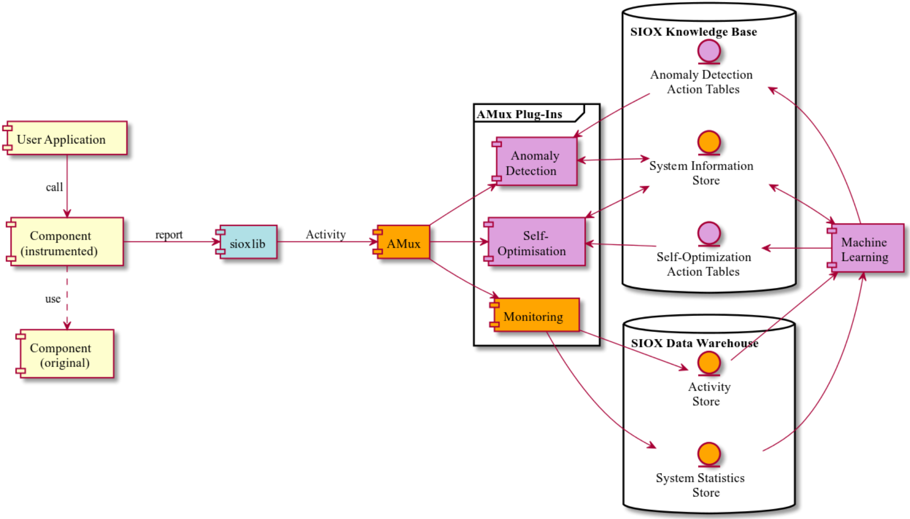
SOPIs are controlled via *Action Tables* in the Knowledge Base.

Machine Learning Plug-Ins (MLPIs)

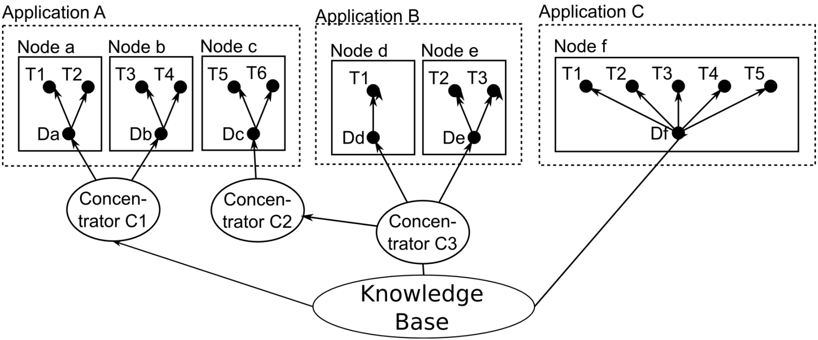


- Run off-line, on-demand
- Analyse data archived in the Data Warehouse with machine learning algorithms or heuristics
- Refine their findings into instructions for their ADPI and/or SOPI
- Store these in a plug-in-specific "action table" in the Knowledge Base
- Action tables may also be built manually (usually to implement common heuristics)

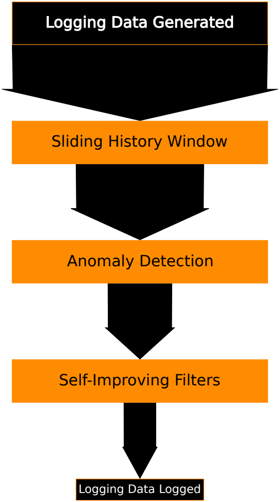
Interplay Between Monitoring and Knowledge Path (1)



Scalability through Hierarchical Data Transport



Damming in the Data Deluge



Logging

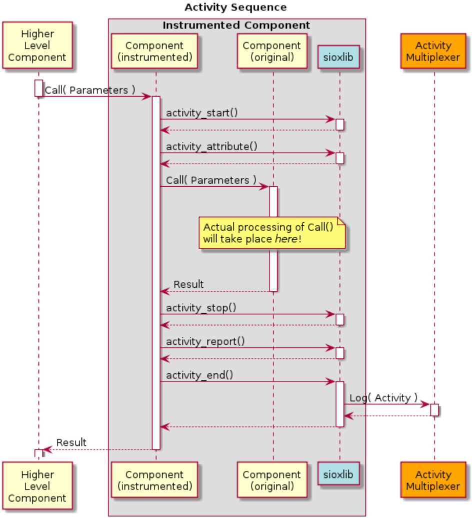
- *every* Activity
- on *every* Level
- *all* of the time

will cause prohibitive overhead.

The SIOX solution:

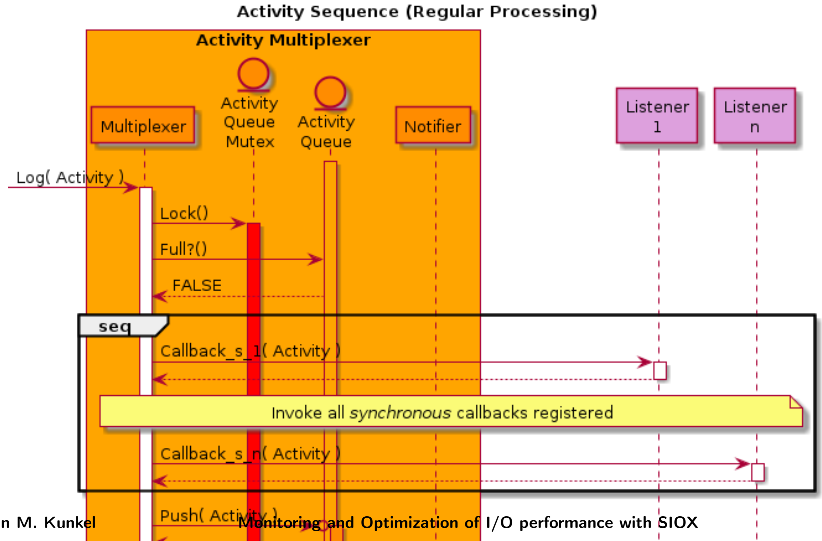
- Log to local window, discard the uneventful
- Focus on anomalies (good & bad)
- Learn from logs to improve filters

Instrumentation and the Activity Multiplexer



Activity Multiplexer Normal Behavior

Click to access the PNG of the design



Activity Multiplexer Throttling (Overflow) Behavior

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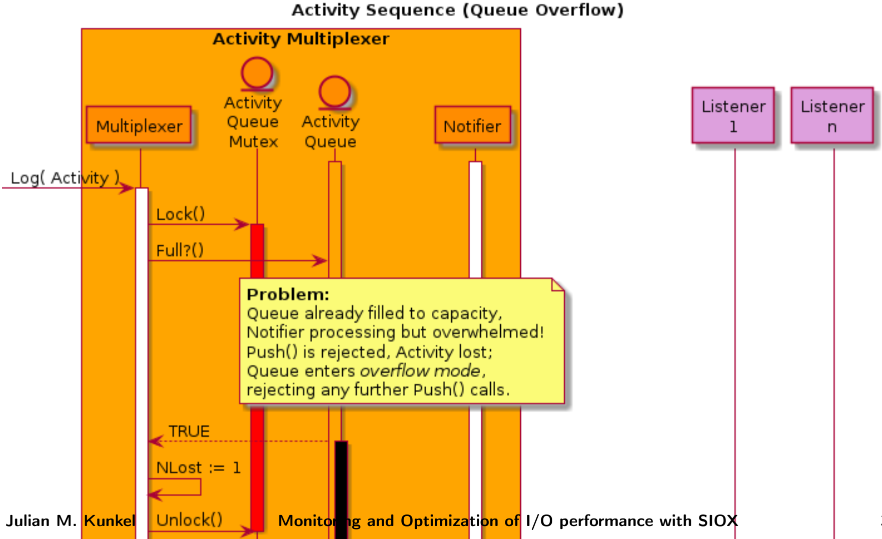
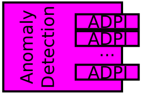


Anomaly Detection Plug-Ins

What ADPIs can do:



- Detect anomalies (exceptional system behaviour)
- Adjust log-levels
- Report recent activity history for analysis
- Mark recent activity sequence for future "watchlist":
  $\Rightarrow$ Timely adjustments to log-levels *before* anomaly recurs
- Make every byte logged count!

ADPIs are controlled via *Action Tables* in the Knowledge Base.

ADPI Example 1

A simple rule-based and stateless plug-in detecting exceptional performance

Mathematical model and Action Table

$$f_{\text{Utilization}}(\text{Component}, \text{Activity}) = \frac{t_{\text{possible}}(\text{Component}, \text{Activity})}{\text{Time}(\text{Activity})}$$

$$t_{\text{possible}} = \frac{\text{Size}(\text{Activity})}{\text{SequentialTransferRate}(\text{Component})} + \text{Latency}(\text{Component})$$

Result	Action
$f_{\text{Utilization}} < 0.10$	Report("Exceptionally low")
$0.10 < f_{\text{Utilization}} < 0.95$	No Action
$0.95 < f_{\text{Utilization}}$	Report("Exceptionally high")

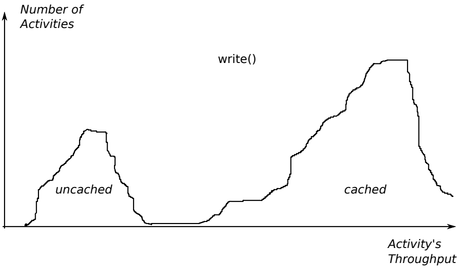
"Component" can be a software layer, a compute node, or a file system.

ADPI Example 2

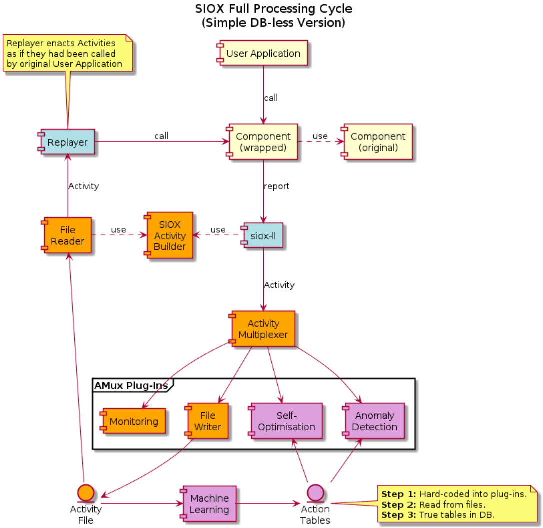
A very simple Action Table implementing a "watchlist"

Action table to detect a write cache filling up

Pattern	Buffer Size
Write(fast) Write(slow)	Report("Cache full")



Prototype (2)



- Application behavior can be recorded in files
- Activities and their metrics are read from files
- Replayer to mimic program behavior
- Machine learning restricted to parameters in heuristics