Feedbacks Control Loops as 1st Class Entities

The SALTY Experiment

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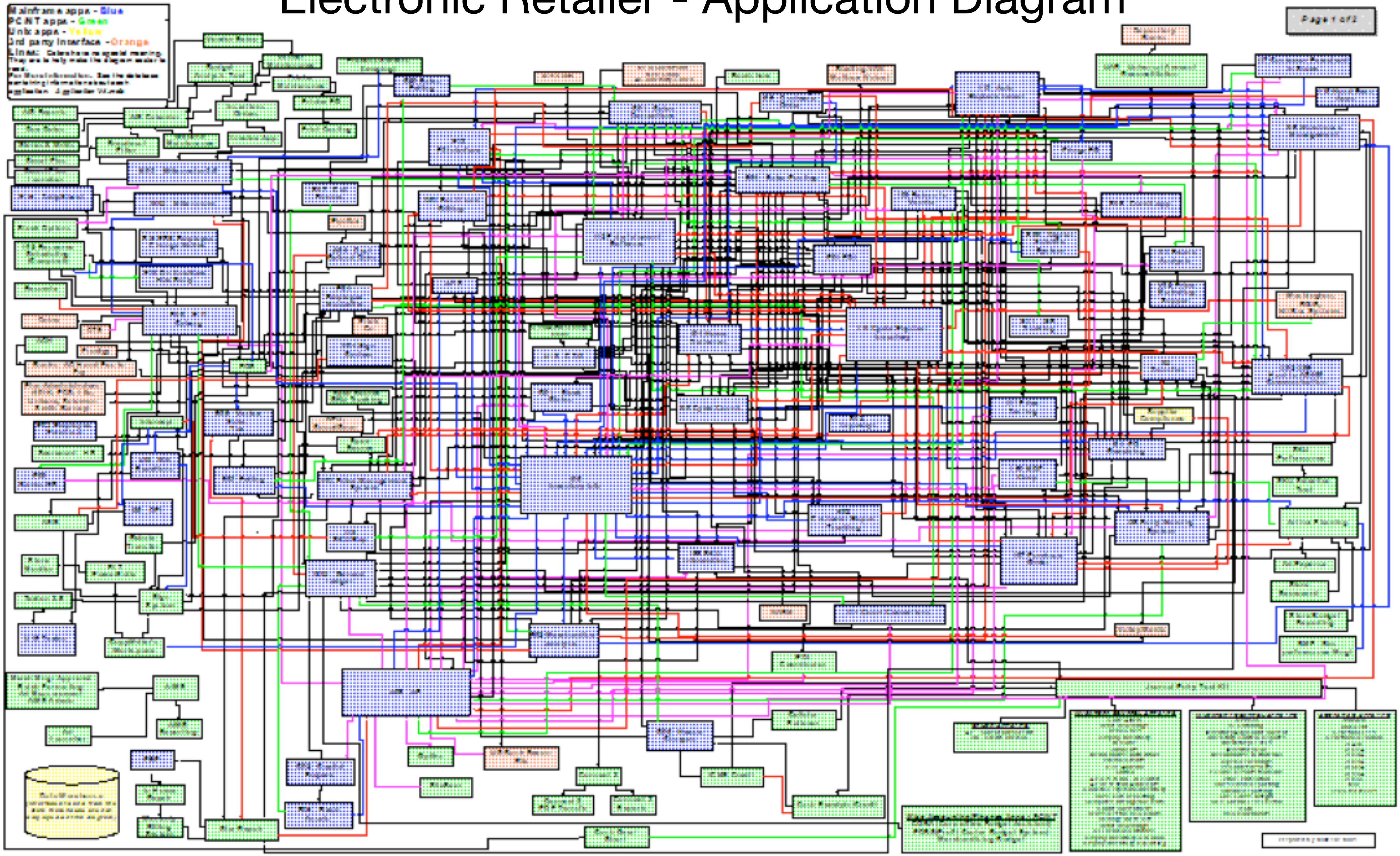
ABOUT MYSELF

- **Middleware platforms (OpenCCM, FraSCAti)**
  - *Component-based Software Engineering*
  - *Aspect-Oriented Programming*
  - *Model-Driven Engineering*
  - *Domain-Specific Languages*

- **Distributed systems**
  - *Mobile/Ubiquitous computing*
  - *Wireless Sensor Networks*
  - *Cloud computing*

Electronic Retailer - Application Diagram



OUR CONTRIBUTIONS SO FAR

Reflective Model | Pluggable Toolchain | Technology Mappings

Feedback control loop

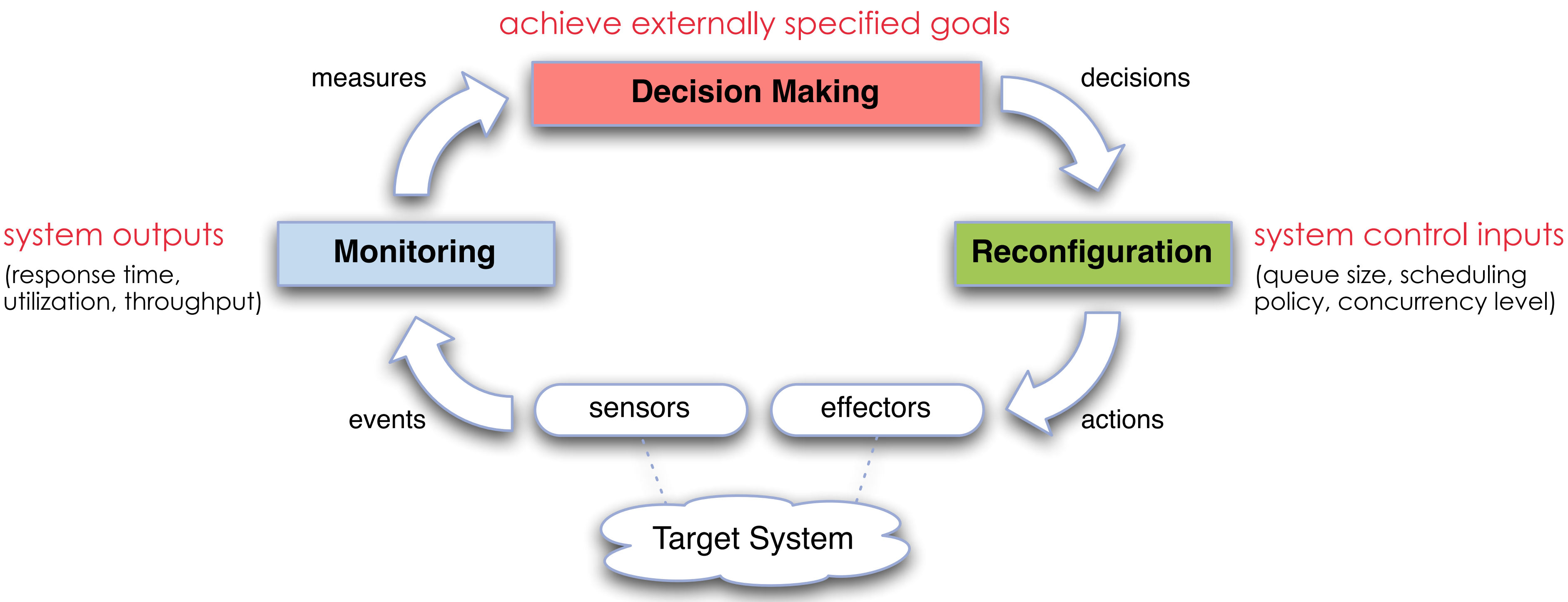
System-centric — *Application-centric* — *Control-centric*

Ubiquitous computing — *Legacy apps* — *Big data*

COSMOS — ***MUSIC*** — ***Cappucino*** — ***SALTY*** — ***Datalyse***

2007 → 2013

FEEDBACK CONTROL LOOP (FCL)

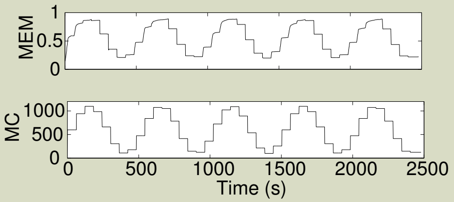


Feedback is a primary mean to enable self-adaptation.

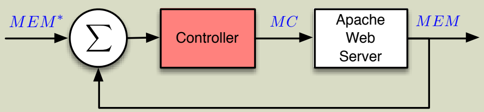
CHALLENGES

- Engineering self-adaptive software systems is challenging
- Example: web server self-optimization

FCL control challenges



$$MEM_{k+1} = 0.485 \cdot MEM_k + 3.63 \times 10^{-4} \cdot MC_k$$



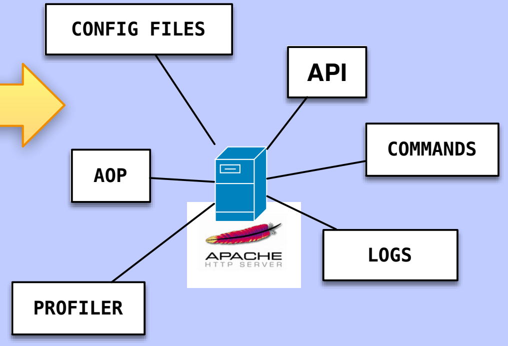
$$u_k = K_P e_k + K_I \sum_{j=1}^{k-1} e_j$$

[Hellerstain et al., 2004]

control engineers

FCL integration challenges

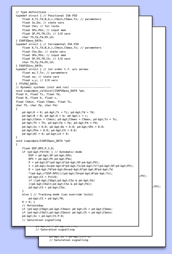
- **Prepare experimental environment**
  - identify system outputs (sensors)
  - identify system control inputs (effectors)



- **Design decision mechanism**
  - data collection
  - model construction and evaluation
  - controller design

software engineers

- **Implementation**
  - integration into target system
  - consistent monitoring
  - coordinated reconfiguration



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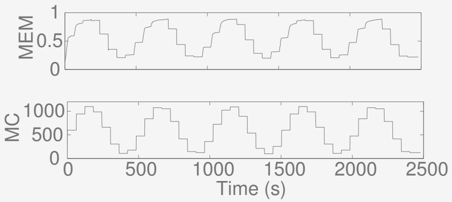

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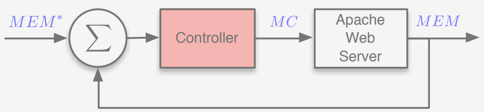

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[Hellerstein et al., 2004]

control engineers

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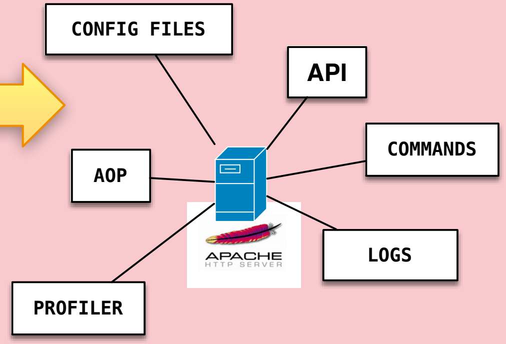

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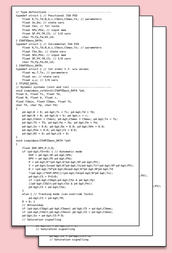


INTEGRATION CHALLENGES

- Forming the **connection** between **an adaptation mechanism** and **a target system**

- Web service content adaptation [Abedlzaher et al. ’99, ’02, ’06]
  - Control theoretical approach
  - **Matlab / C implementation directly in Apace code base**

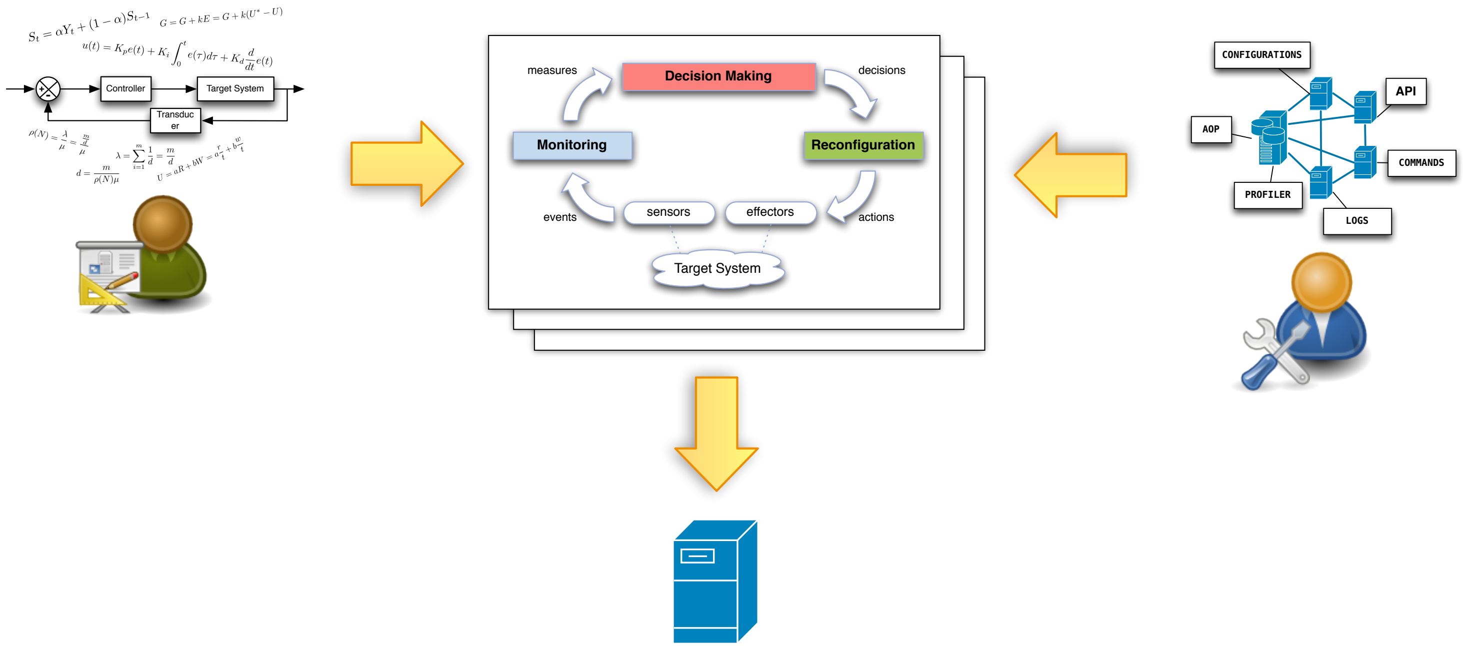
- Self-healing in workflow execution on grids [Silva et al. ’13]
  - Tuned analytical model
  - **Java implementation directly in a workflow enacting engine**

- Scaling Hadoop Clusters [Berekmeri et al.’14]
  - Control theoretical approach
  - **Matlab / Bash**

- Extensive handcrafting of a **non-trivial implementation** code
- **Low-level abstraction** - limited verification, reuse, maintainability
- Giving rise to **accidental complexities**

OVERVIEW

Systematic integration of self-adaptive mechanisms into software systems through architecture models and model-driven engineering techniques.



Generality | Visibility | Reusability | Distribution | Complex control | Tooling

REQUIREMENTS

Derived requirements for integrating self-adaptation into software systems.

Generality

- Domain-agnostic
- Technology-agnostic

Reusability

- Reusable FCL parts across adaptation scenarios

Complex control

- Composition
- Reflection

Visibility

- Explicit FCLs, their process and interactions
- Verification support

Distribution

- Remote distribution of FCL

Tooling

- Prototyping
- Automating

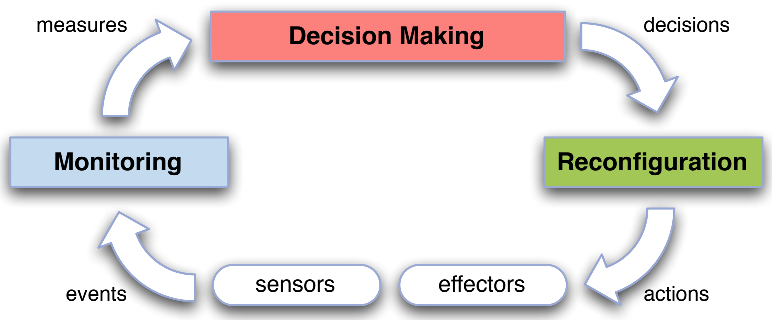
[Babaoglu et al.'05, Salehie et al.'09, Cheng et al.'09, Brun et al.'09, Muller et al'09]

1

Feedback Control Definition Language

FEEDBACK CONTROL DEFINITION LANGUAGE

1. Raise the level of abstraction
2. Fine-grained decomposition of FCL elements
3. Explicit interactions
4. Provide reflection capabilities
5. Embed remoting

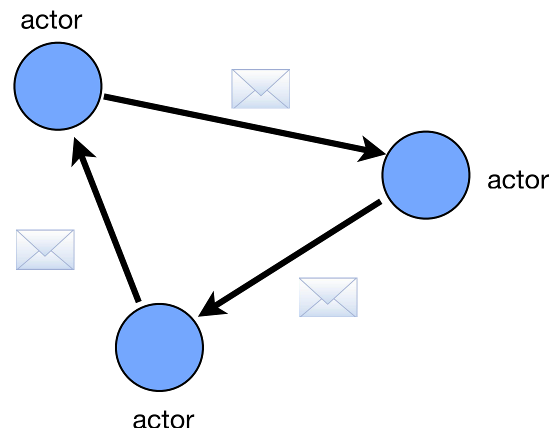


Feedback Control Loop

- Sequence of interconnected processes
- Input × State → Output
- Reactive
- Concurrent
- Dynamic

Domain-Specific Modeling

- Abstraction
- Automation
- Analysis



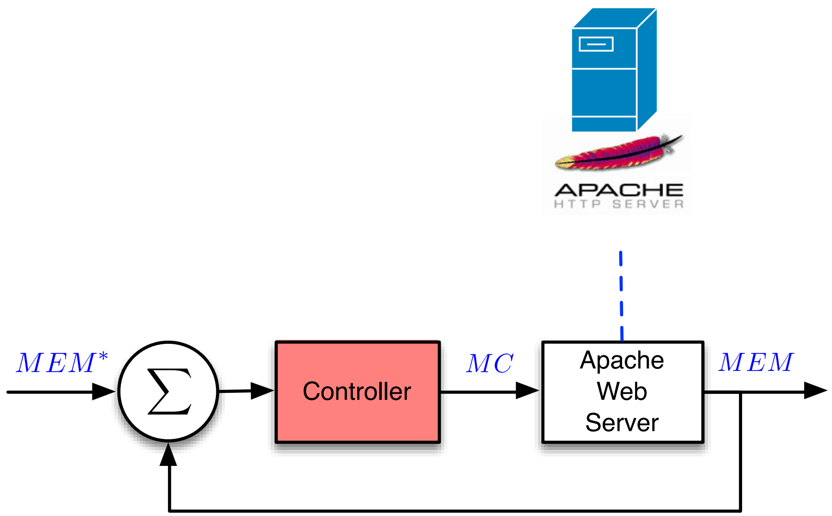
The Actor Model

- Message passing actor networks
- Message × State → Message(s)
- Reactive
- Concurrent
- Dynamic
- Scalable
- Remoting through location transparency

Inria

FEEDBACK CONTROL DEFINITION LANGUAGE - IN A NUTSHELL

Apache adaptation example - *adjusts the maximum number of connections to be processed simultaneously (MC) based on the difference between reference (MEM*) and measured memory usage (MEM) [Hellerstain et al.'04].*



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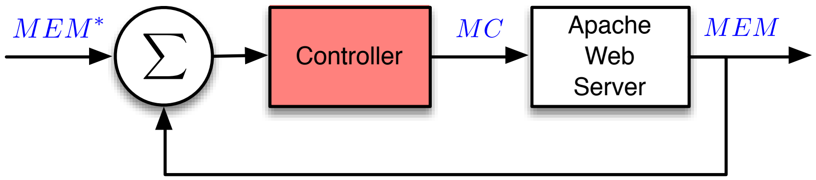
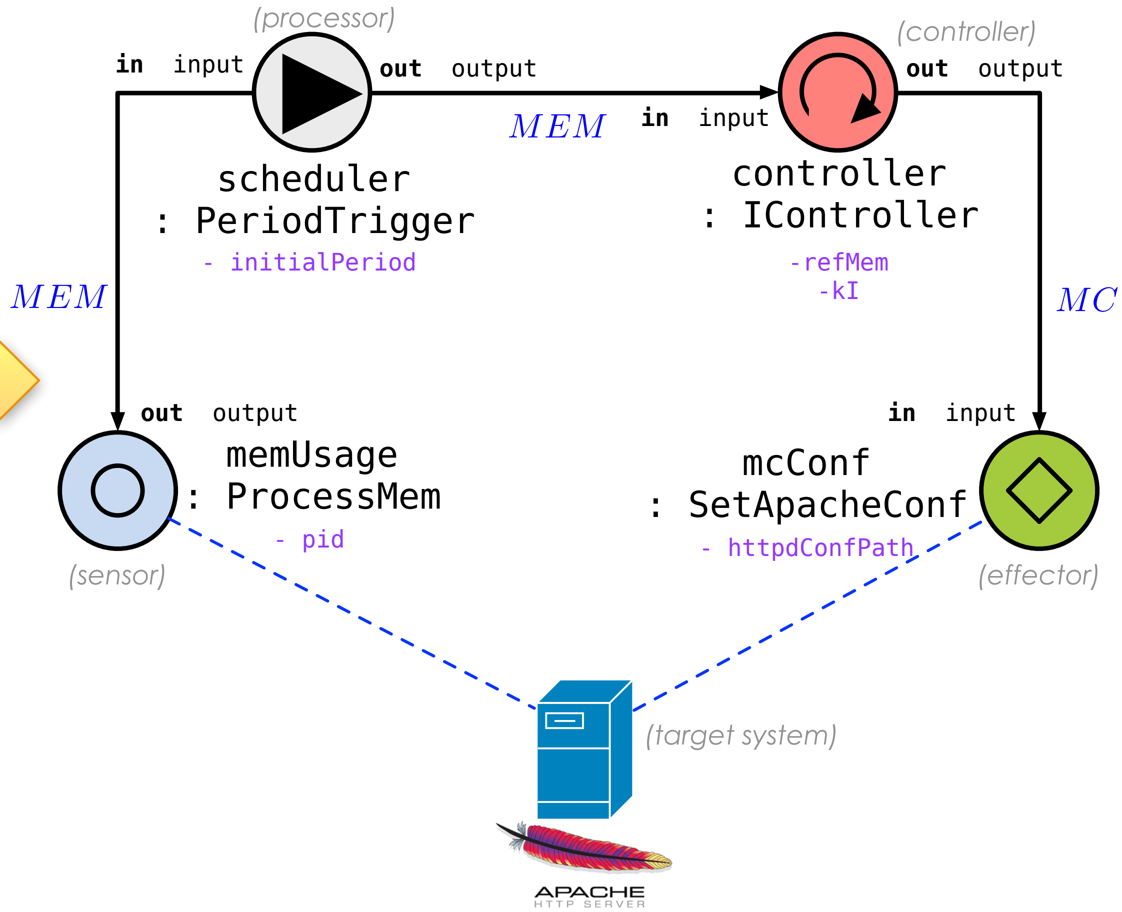


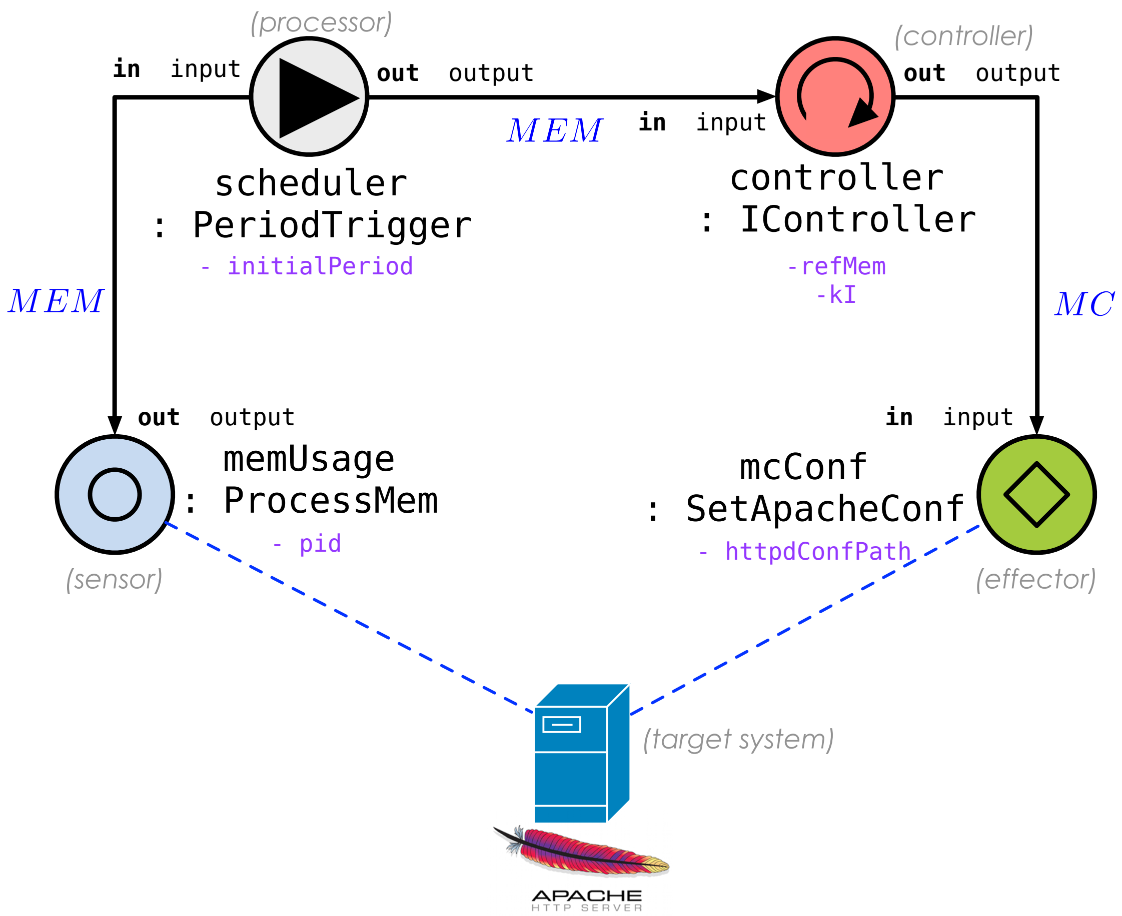


Graphical Syntax

FEEDBACK CONTROL DEFINITION LANGUAGE - IN A NUTSHELL

Adaptive Element

- Actor-like component
  - Sensors
  - Effectors
  - Processors
  - Controllers
- Input/output ports & properties
- Active / passive
- Implementation
  - Imperative code (e.g. Java)
  - CEP Rules (e.g. Drools)
  - STM (e.g. bzr/heptagon)
  - Matlab
  - BASH
  - …



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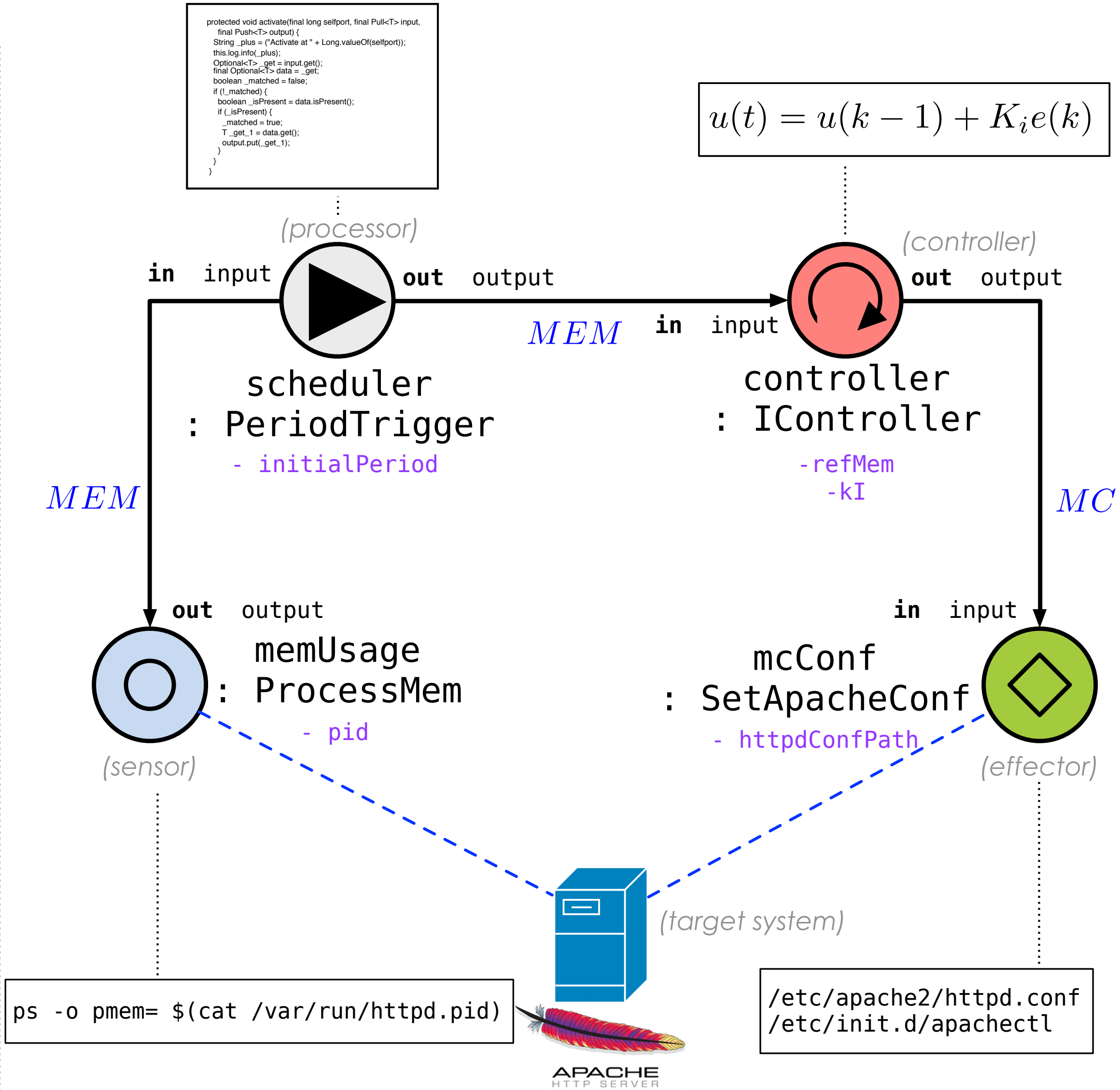

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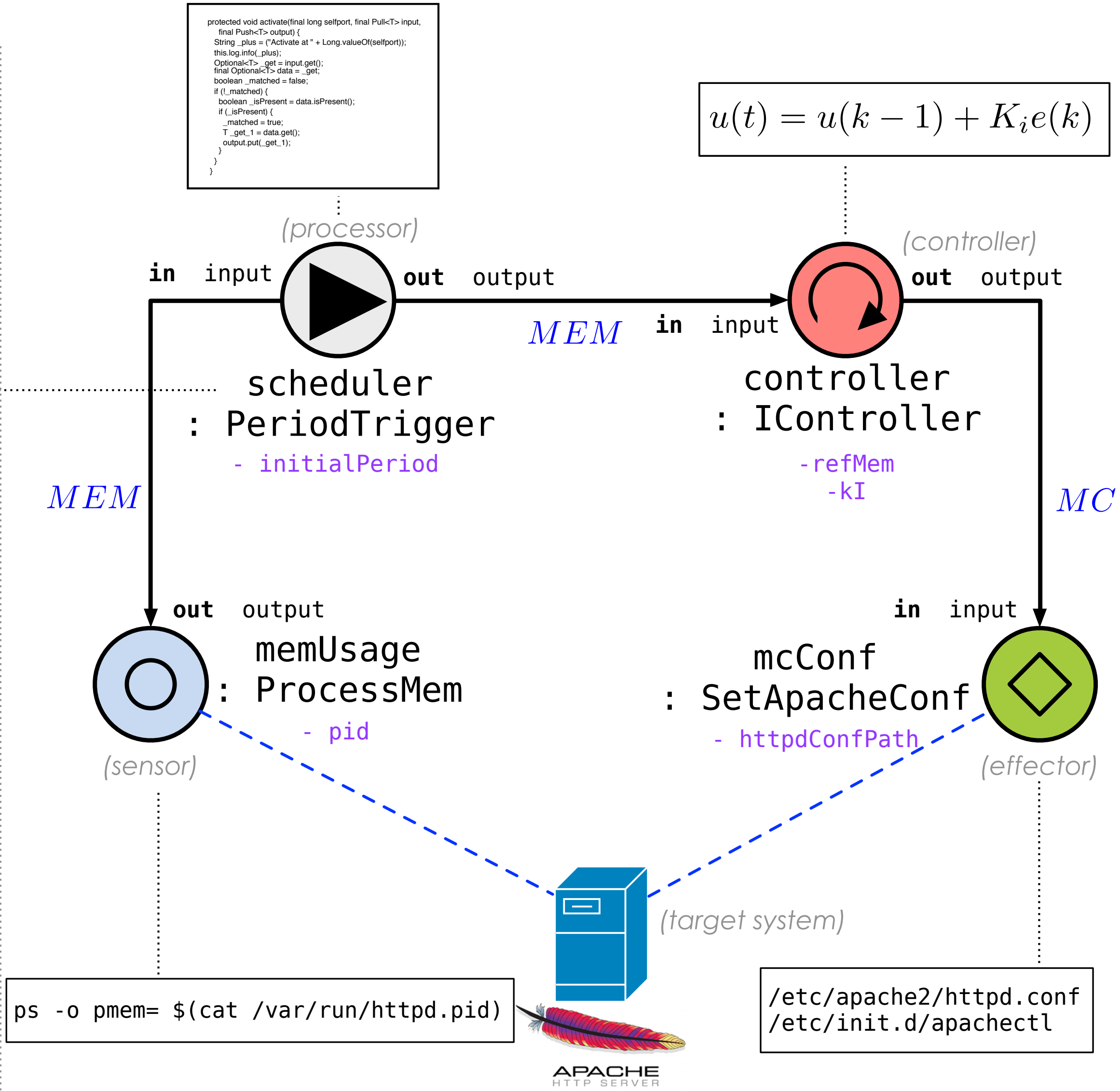
  - ...
- Interaction contracts

$$\alpha = \langle\, self; \Downarrow (\mathtt{input}); \Uparrow (\mathtt{output?})\,\rangle$$



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$$\alpha = \langle\, self; \Downarrow(\mathtt{input}); \Uparrow(\mathtt{output?})\,\rangle \;||\; \langle\, \Uparrow(\mathtt{setPeriod}); \emptyset; \Uparrow(\mathtt{period})\,\rangle$$

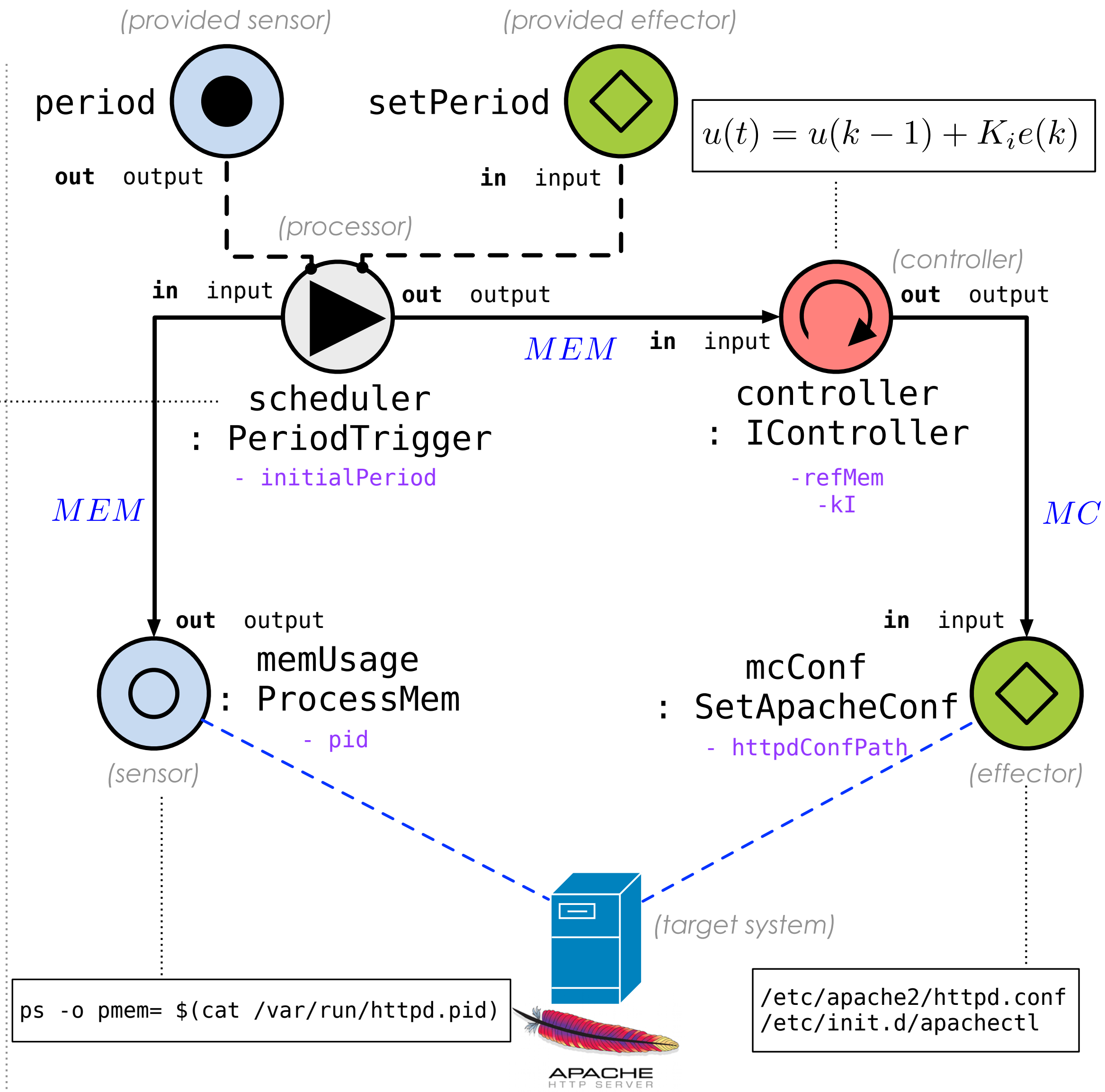

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ILLUSTRATION OF WEB SERVER QoS ADAPTATION IMPLEMENTATION

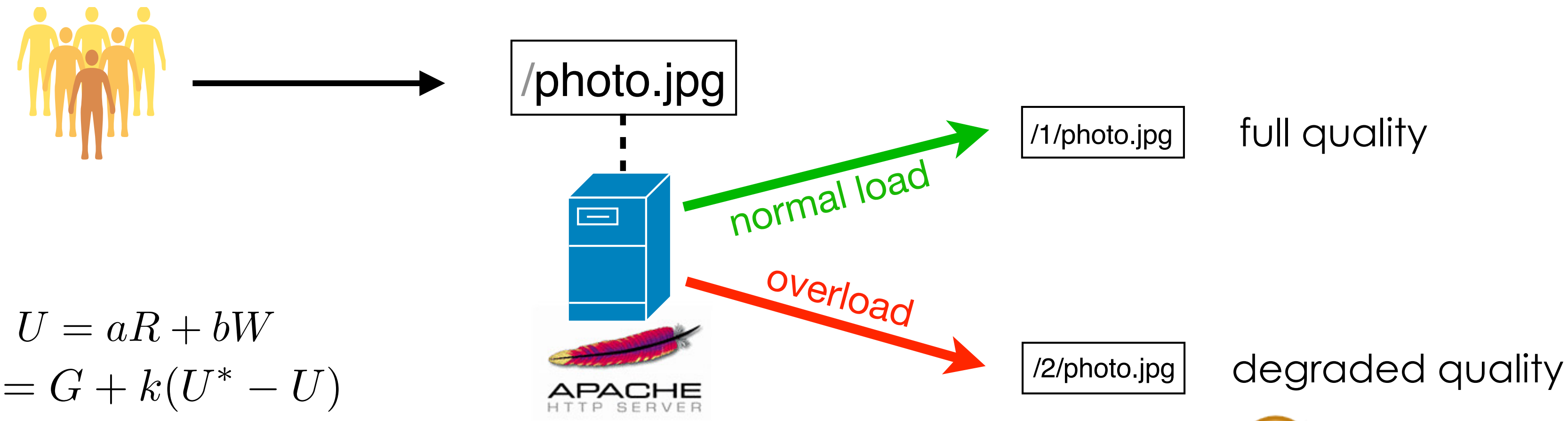
LOCAL CONTENT DELIVERY ADAPTATION

QoS management control of web servers by content delivery adaptation

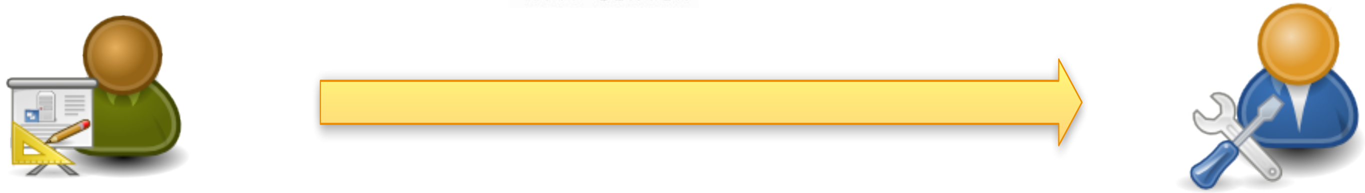
Goal: maintain server load around some pre-set value

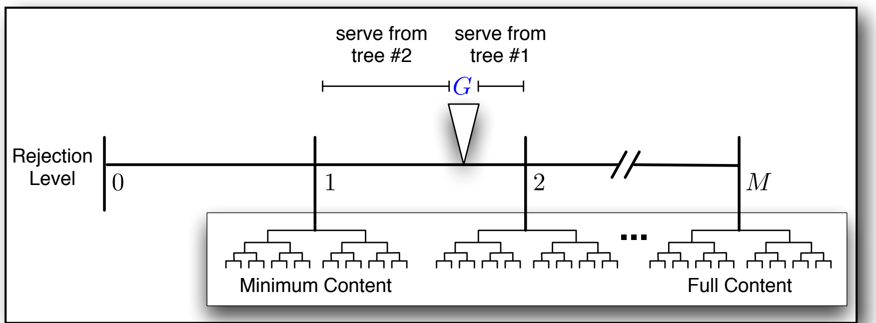
Idea: service time = fixed overhead + data-size dependent overhead

Prerequisite: preprocessed content (different quality and size)



$$U = aR + bW$$
$$G = G + k(U^* - U)$$





Using FCDL

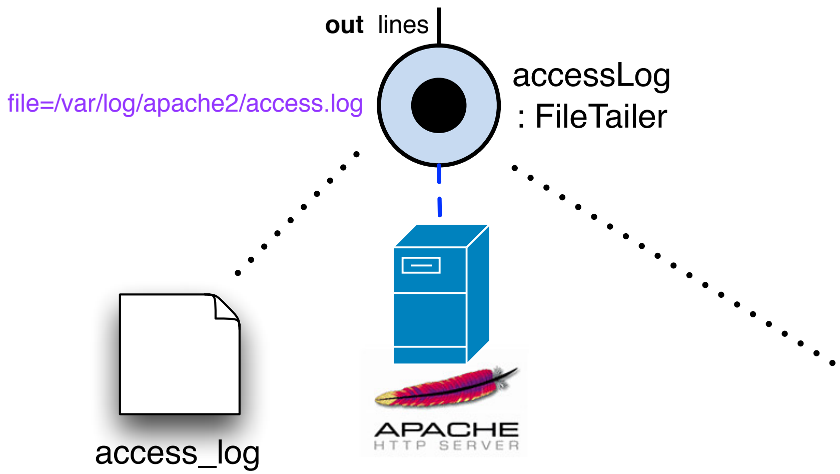
Generality | Visibility | Reusability

Distribution | Complex control

Abdelzaher et al., 1999, 2002

LOCAL CONTENT DELIVERY ADAPTATION

1 Compute the number of requests (r) and size of responses (w)




```
active sensor FileTailer {
  push out port lines: String

  property file: String
}
```

LOCAL CONTENT DELIVERY ADAPTATION

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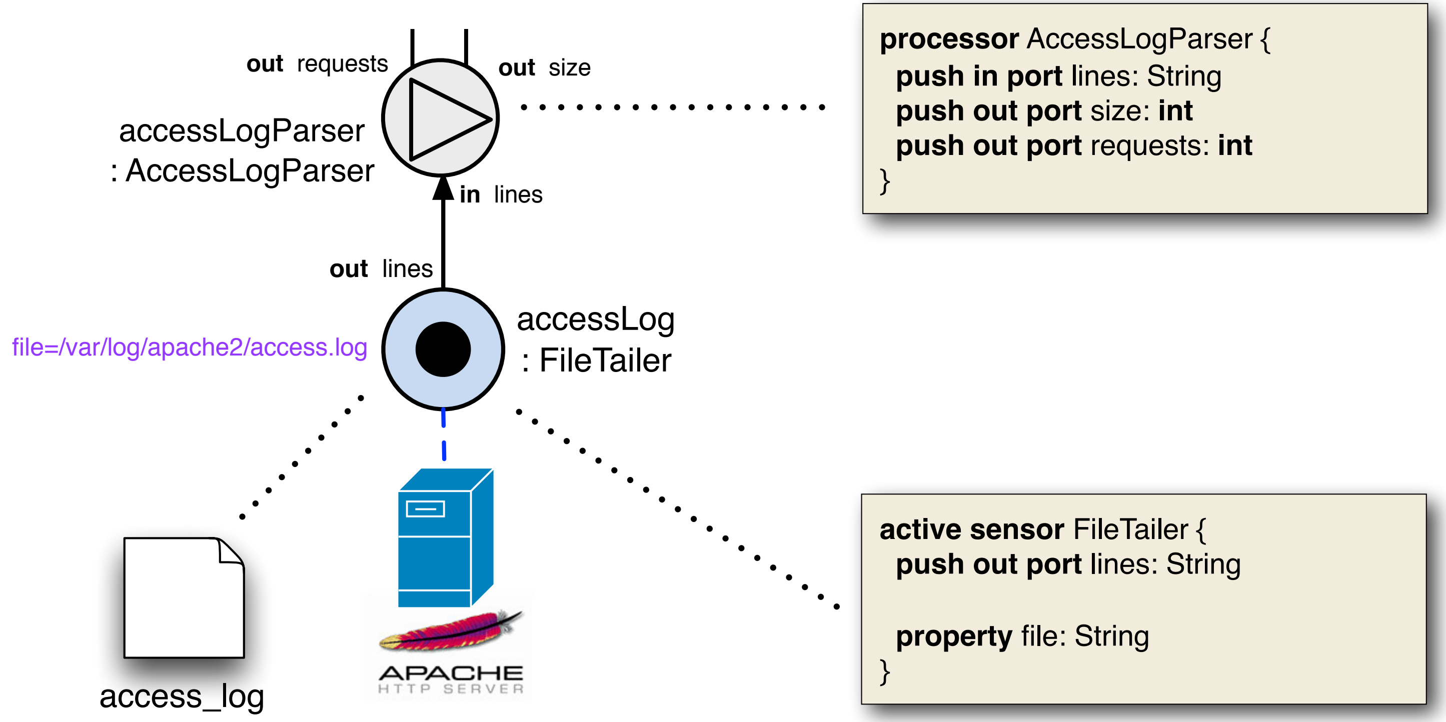
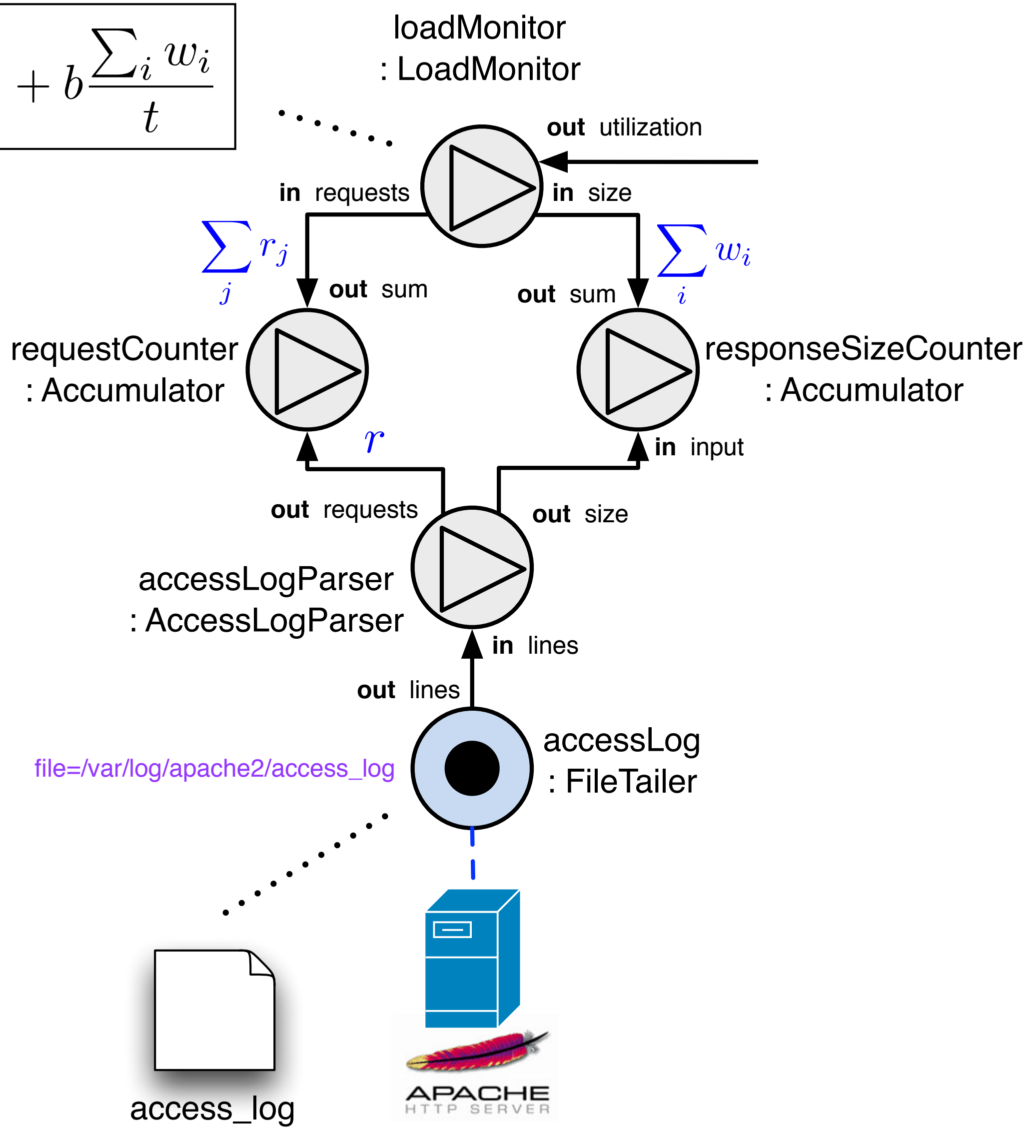


LOCAL CONTENT DELIVERY ADAPTATION

2 Compute the requests rate (R), bandwidth (W) and utilization (U)

$$U = aR + bW = a\frac{\sum_j r_j}{t} + b\frac{\sum_i w_i}{t}$$



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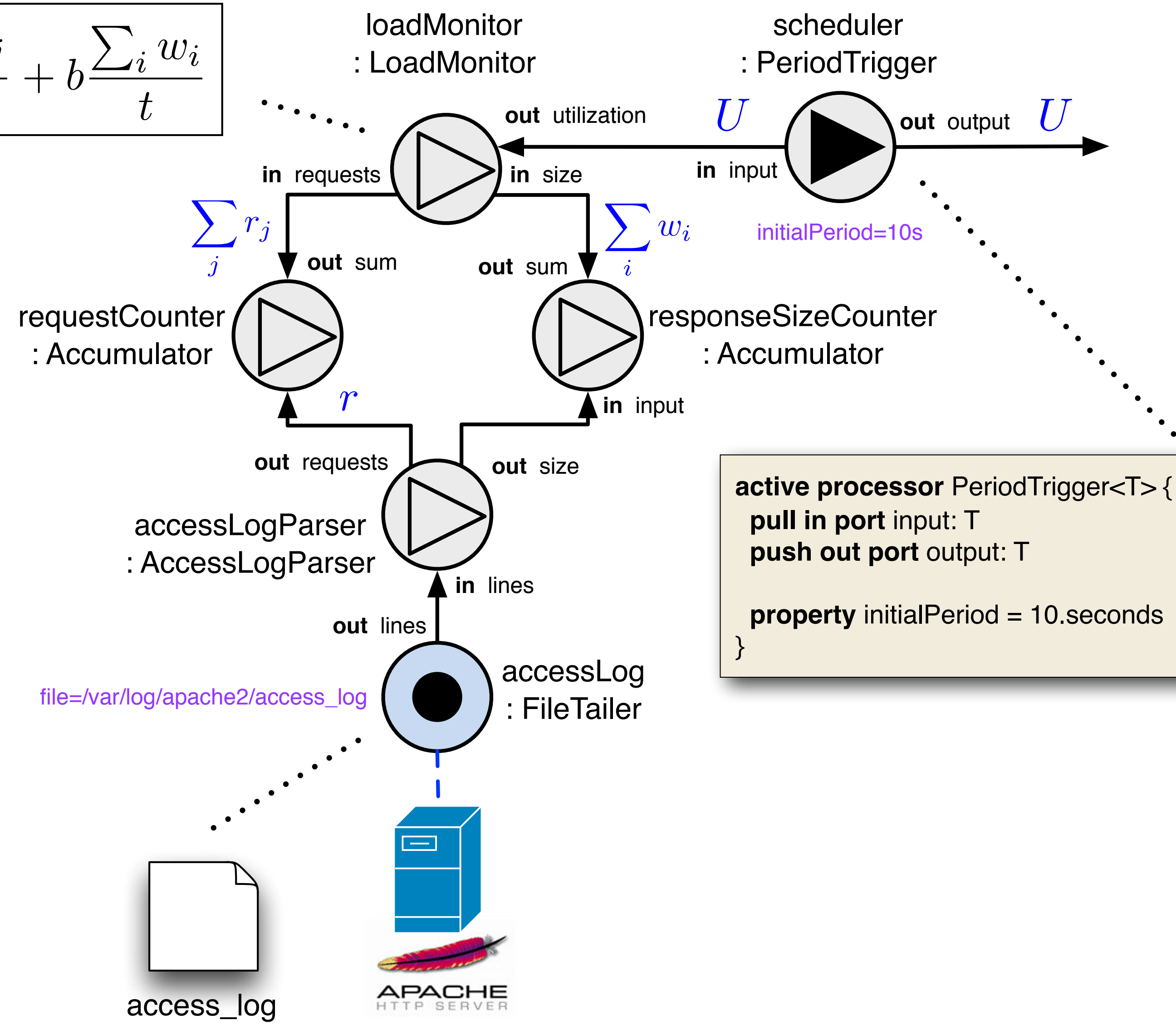
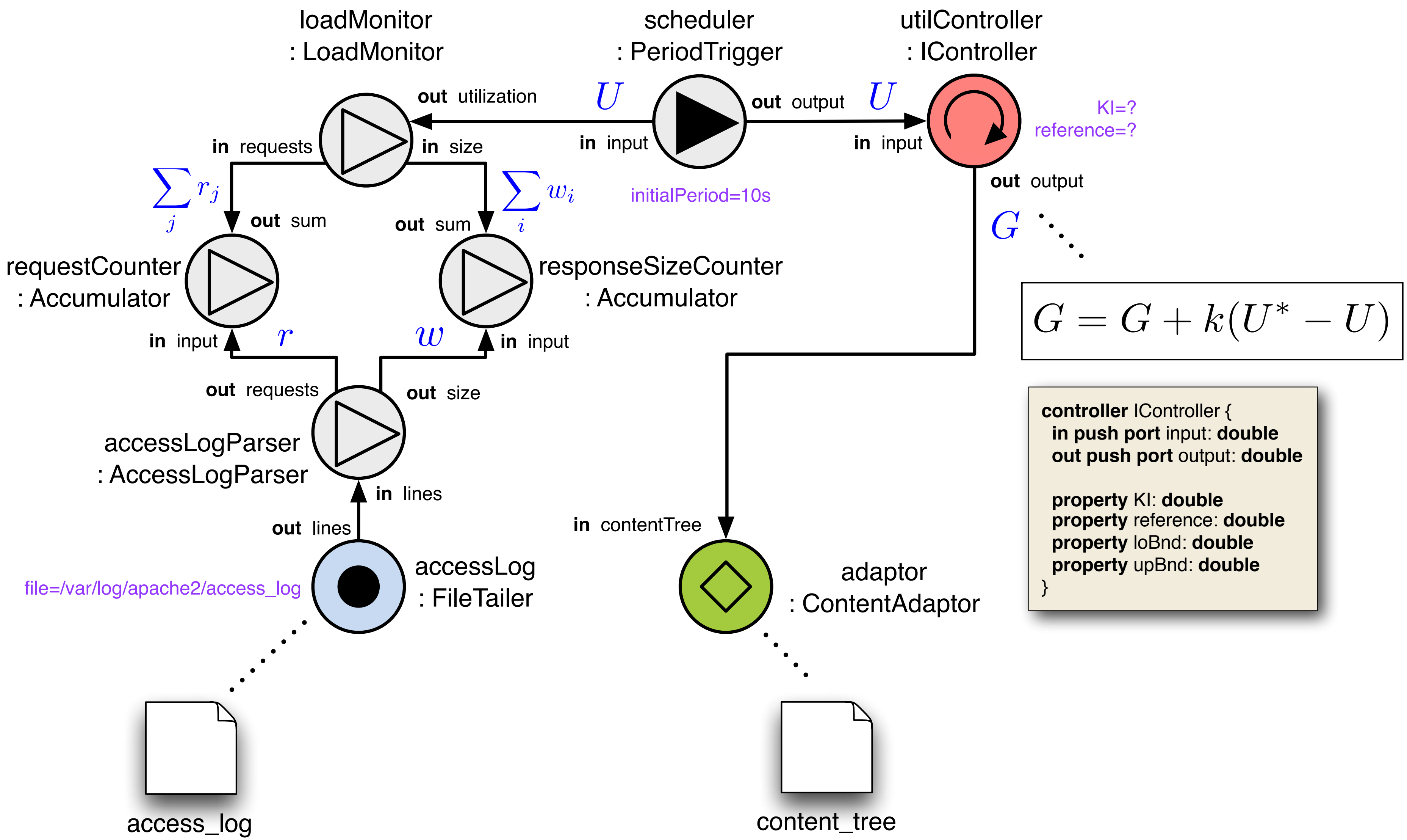


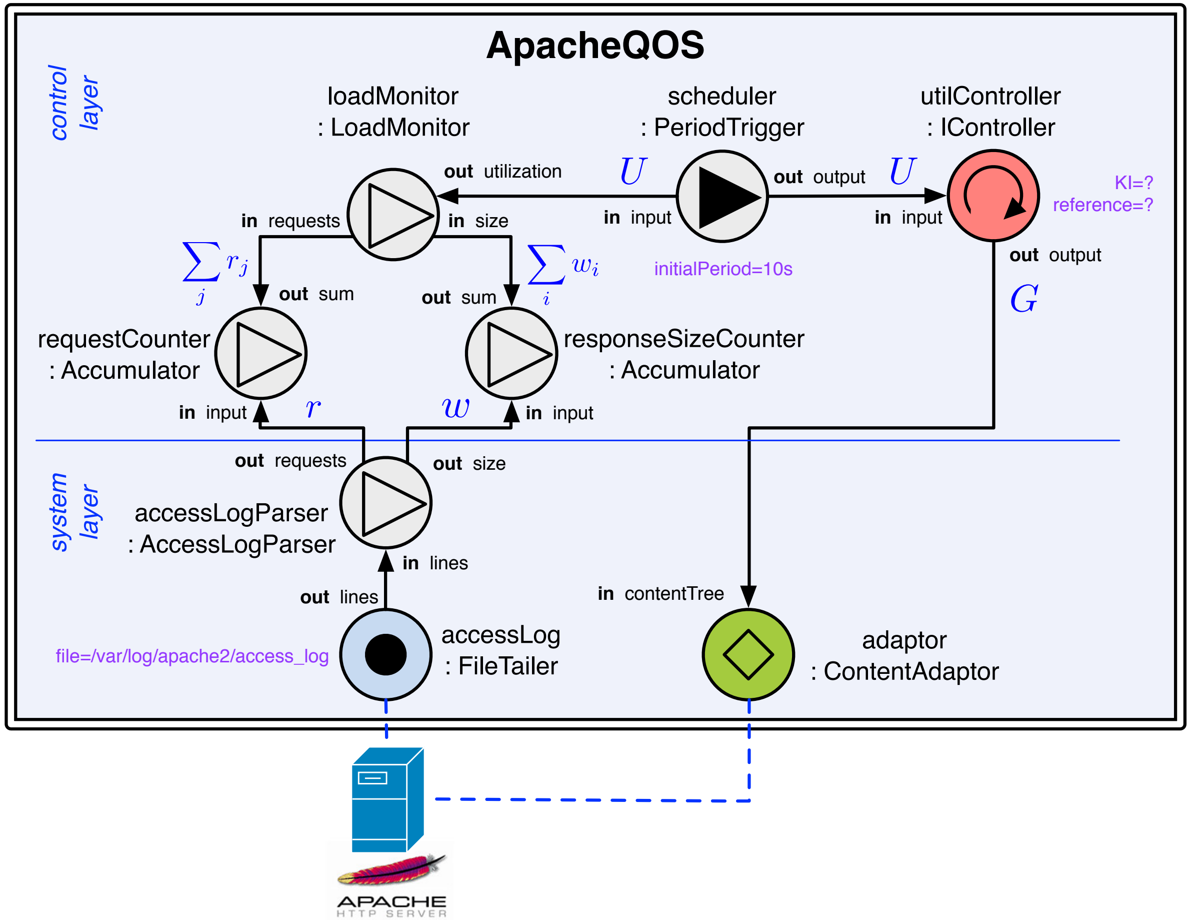

```
active processor PeriodTrigger<T> {
  pull in port input: T
  push out port output: T

  property initialPeriod = 10.seconds
}
```

LOCAL CONTENT DELIVERY ADAPTATION

3 Compute severity of adaptation (G)



LOCAL CONTENT DELIVERY ADAPTATION - COMPLETE MODEL




```
composite ApacheQOS {

  feature accessLog = new FileTailer {
    file = "/var/log/apache2/access_log"
  }

  feature accessLogParser = new AccessLogParser
  feature requestCounter = new Accumulator
  feature responseSizeCounter = new Accumulator
  feature loadMonitor = new LoadMonitor
  feature scheduler = new PeriodTrigger<Double>
  feature utilController = new IController {
    reference = 0.8
  }
  feature adaptor = new ContentAdaptor

  connect accessLog.lines to
    accessLogParser.lines
  connect accessLogParser.size to
    responseSizeCounter.input
  connect accessLogParser.requests to
    requestsCounter.input
  connect requestCounter.output to
    loadMonitor.requests
  connect responseSizeCounter.output to
    loadMonitor.size
  connect loadMonitor.utilization to
    scheduler.input
  connect scheduler.output to
    utilController.utilization
  connect utilController.contentTree to
    adaptor.contentTree

}
```

LOCAL CONTENT DELIVERY ADAPTATION - COMPOSITION

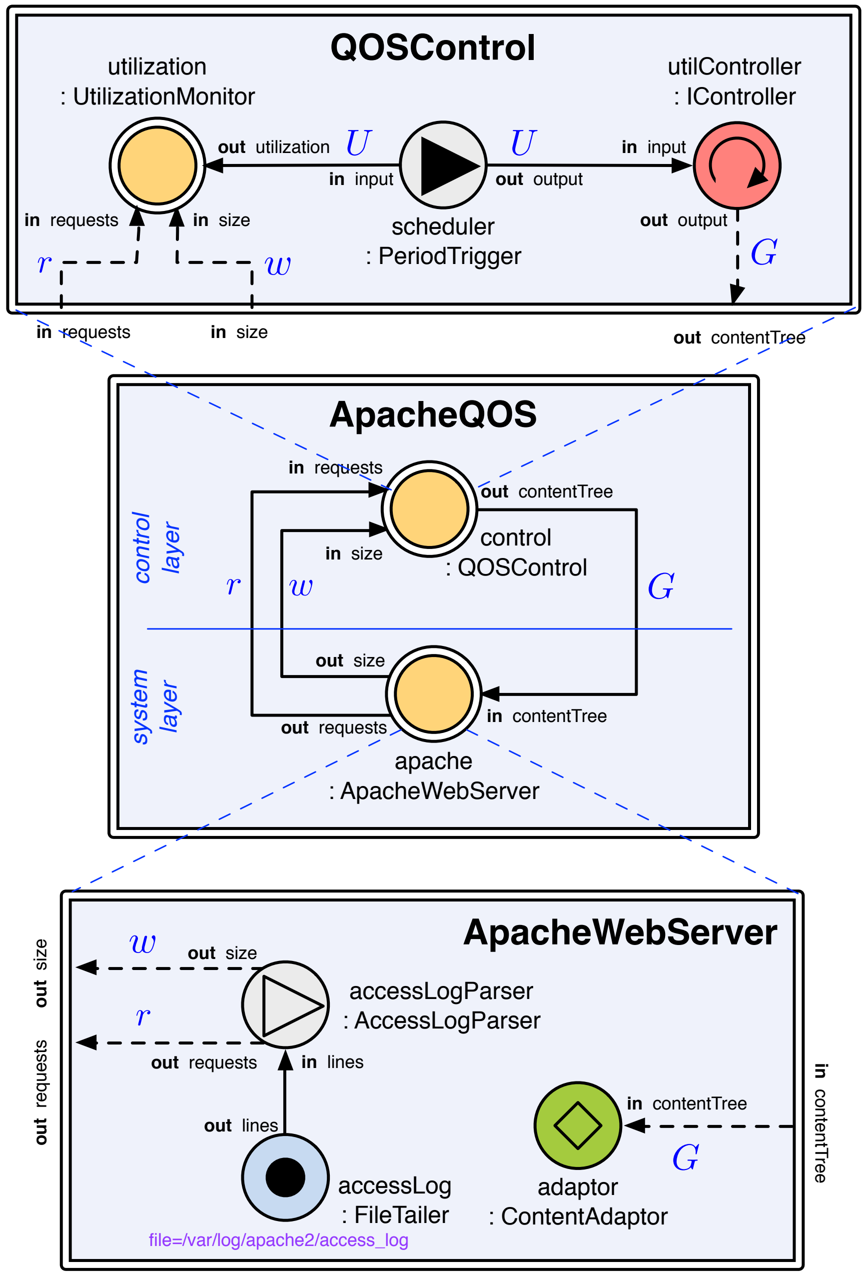


ILLUSTRATION - SYSTEM IDENTIFICATION

- Support for FCL design - black-box modelling
- **Open control loops** for data collection

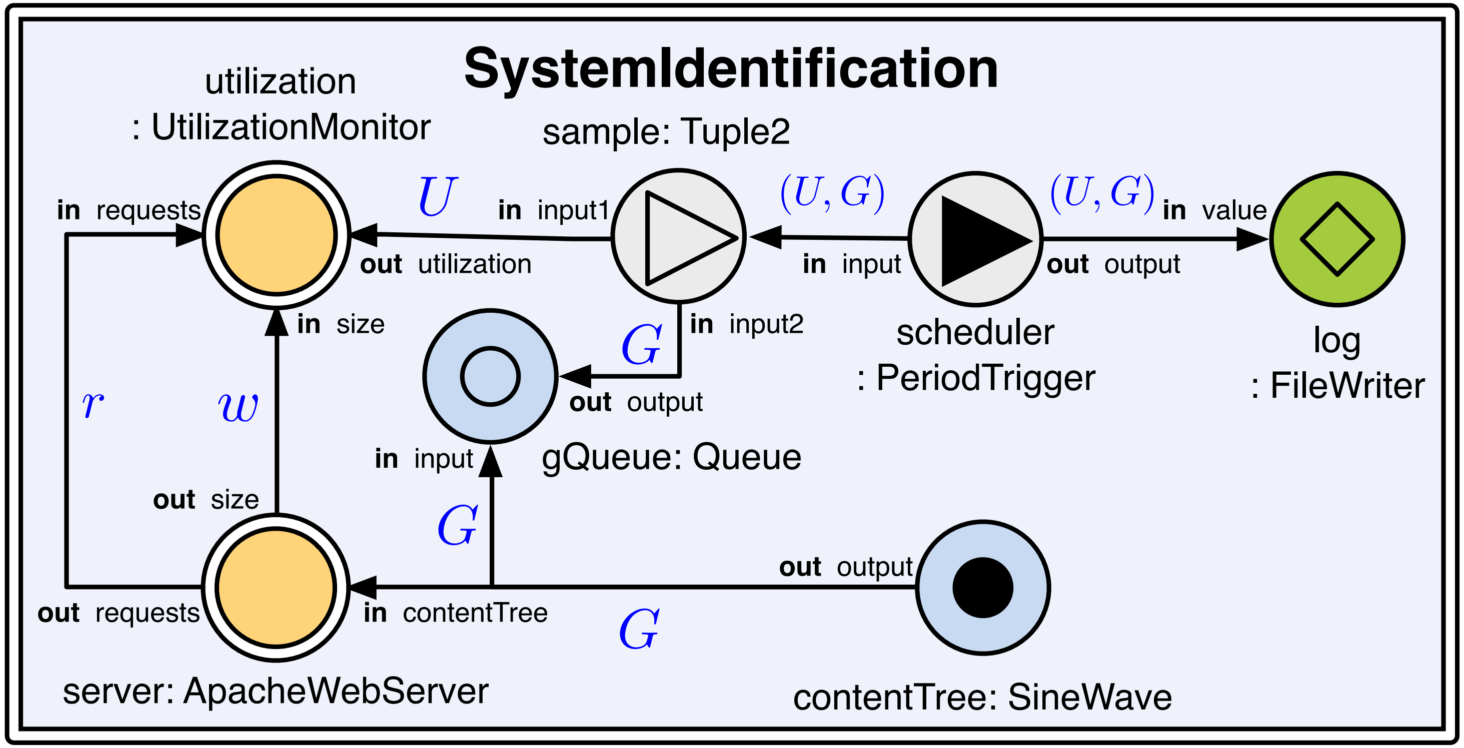
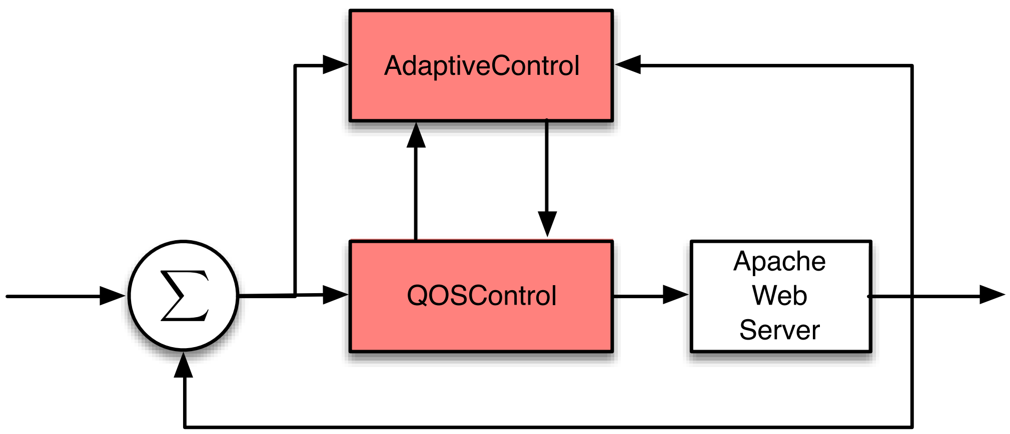


ILLUSTRATION - ADAPTIVE CONTROL

- Using the reflection support for **adaptive control**



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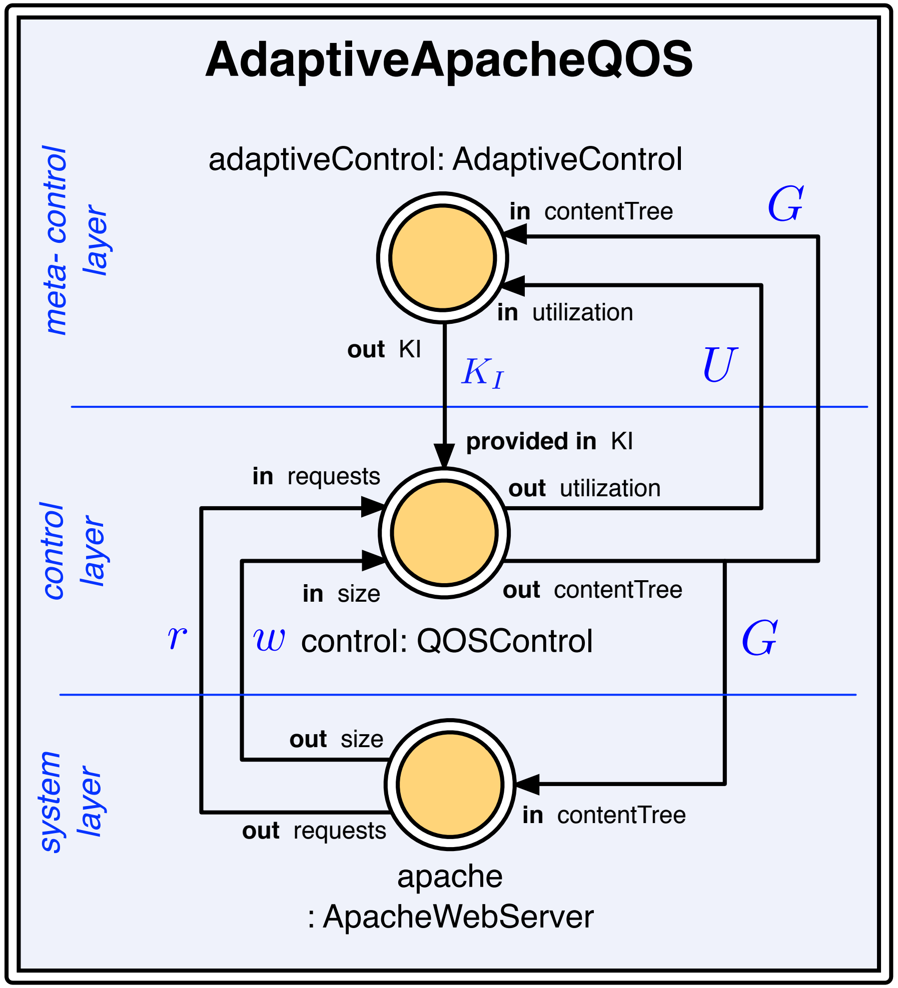

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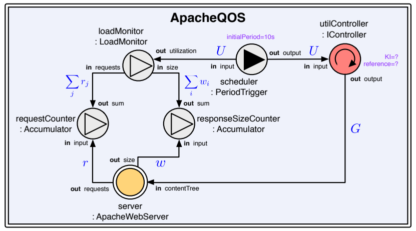
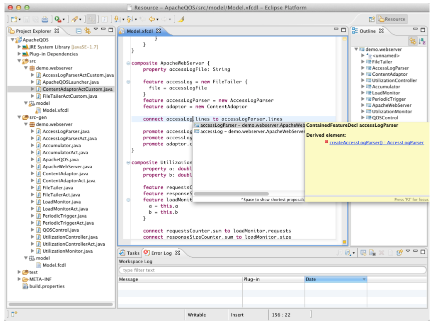
The ACTRESS Modeling Environment

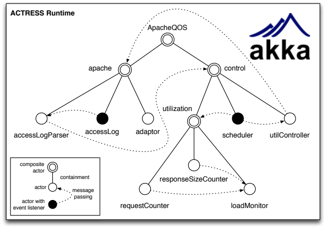
IMPLEMENTATION

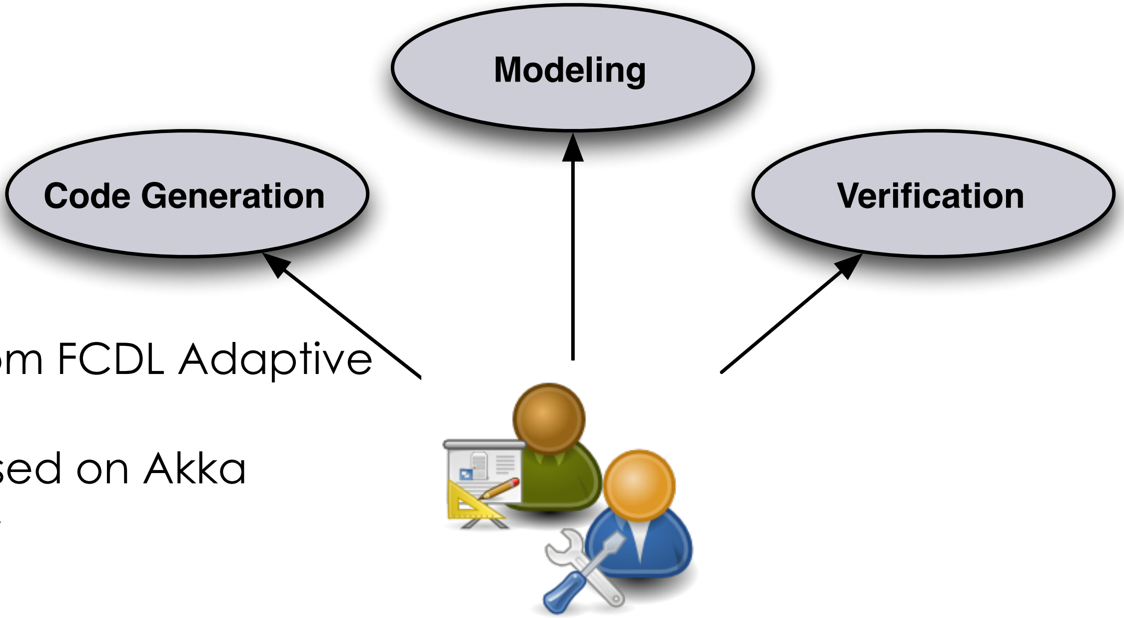
- Reference implementation of FCDL based on Eclipse Modeling Framework
- Eclipse IDE-based prototype to facilitate the use of FCDL - ACTRESS





- Textual DSL for authoring FCDL models
- Modularity, Java interoperability, Xbase
- Eclipse IDE support





- Generates Actors from FCDL Adaptive Elements
- ACTRESS runtime based on Akka
- Maintain traceability

ACTRESS - VERIFICATION SUPPORT

- **Model well-formedness through meta-model constraints**
  - Data-types, port connections, required properties, …

```
@OCL(invDifferentSource="self.ports
->sel                                              ports
->col
->col
->asS
")
processor LoadMonitor {
```

$$\Box(\texttt{accessLogParser}_{activate} \rightarrow (\Diamond\, \texttt{utilController}_{activate}))$$

- **User-defined structural constraints, e.g., xFCDL OCL annotations**

- **User temporal constraints**
  - Connectivity, reachability
  - FCDL to PROMELA transformation verified by SPIN model checker

4
Conclusions

SUMMARY

- Combining self-adaptive software systems with principles of MDE to provide **systematic** and **tooled approach** for **integrating adaptation mechanisms** into **software systems**

- Address ACTRESS limitations - MPS-based implementation
- Improvements in FCDL (e.g. data units, IO assertions, modeling assumptions)
- A library of reusable Adaptive Elements
- Executable models using Ptolemy 2
- Integration with Matlab/Simulink/Modelica
- Explore models@run.time for a systematic implementation of touchpoints

Thank you

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