INVENTORS FOR THE DIGITAL WORLD

Integrating Adaptation Mechanisms Using Control Theory Centric Architecture Models: A Case Study

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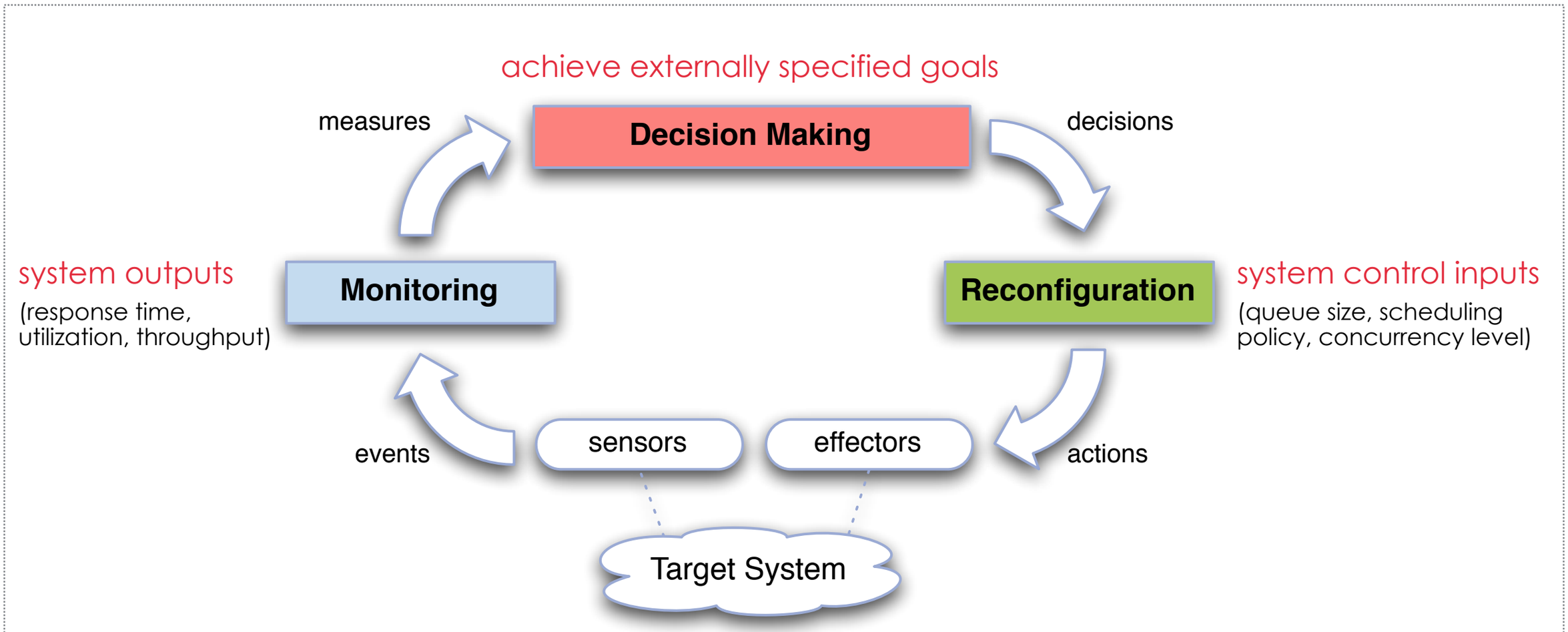
SELF-ADAPTIVE SOFTWARE SYSTEMS, FEEDBACK CONTROL

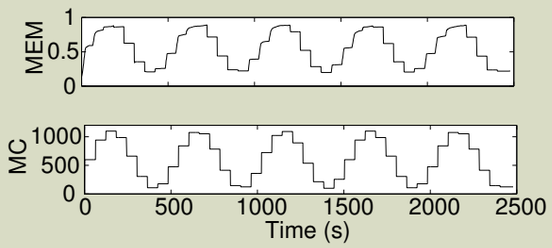
- Increasing complexity of software systems, uncertain operating environment
- A shift towards self-adaptive software systems
  - *systems adjusting themselves in accordance with higher-level goals*
- Feedback control loops (FCLs) provide a generic mechanism for engineering self-adaptive software systems



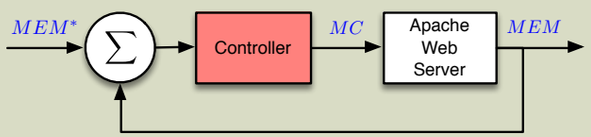
CHALLENGES

- Engineering self-adaptive software systems is challenging
- Example: web server self-optimization (MC based on MEM)

FCL control challenges



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



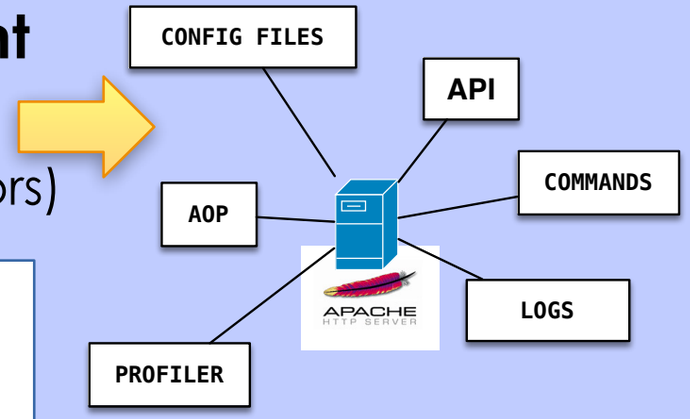
$$u_k = K_P e_k + K_I \sum_{j=1}^{k-1} e_j$$

[Hellerstein et al., 2004]

control engineers

FCL integration challenges

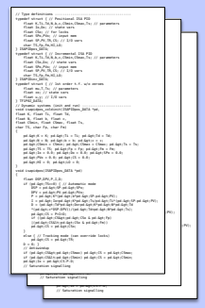
- **Prepare experimental environment**
  - identify system outputs (sensors)
  - identify system control inputs (effectors)



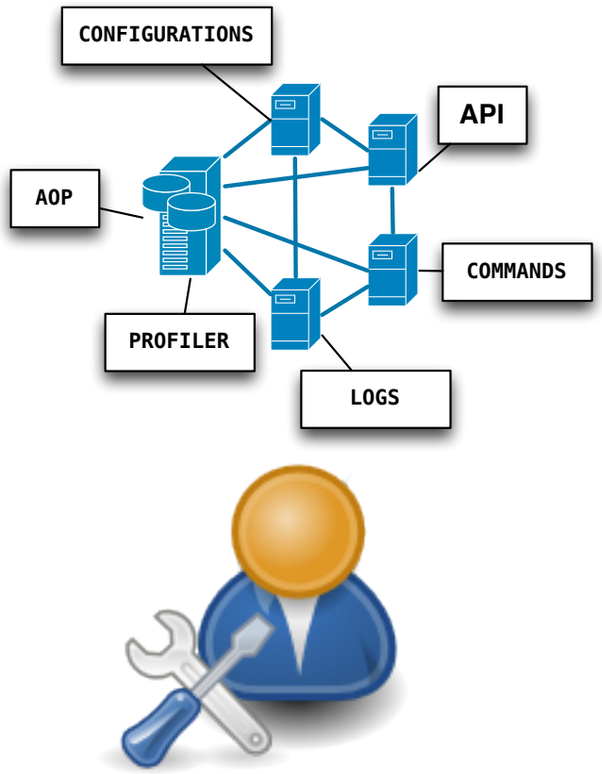
- **Design decision mechanism**
  - data collection
  - model construction and evaluation
  - controller design

software engineers

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



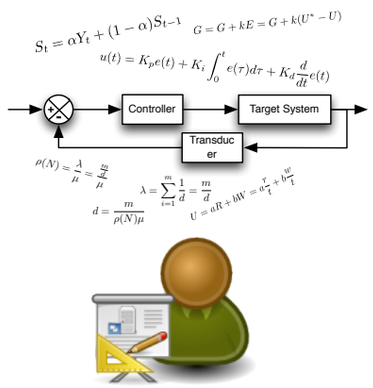
INTEGRATING ADAPTATION MECHANISMS

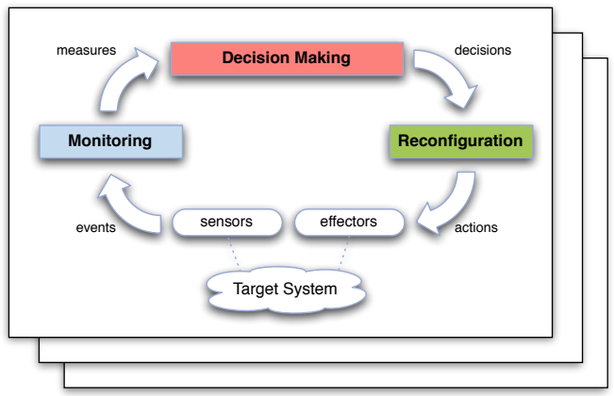


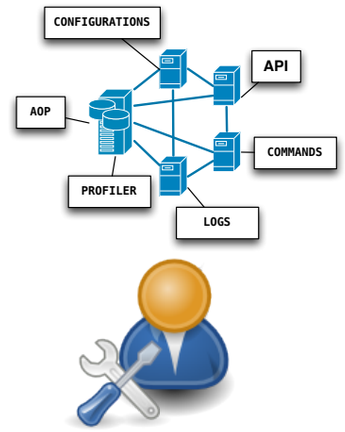
- **Adhoc Implementations**
  - Extensive handcrafting of non-trivial code
  - Low level of FCL abstraction
  - Low FCL visibility
  - Limited verification and reasoning
  - **Giving raise to accidental complexities**
- **Reusing and adapting existing work**
  - Often target specific types of adaptation problems [Bertran'12]
  - Require the use of certain adaptation mechanism [Garlan'04]
  - Applicable to single domain [Rouvoy'08] or technology [Asadollahi'09]
  - Do not support remoting or complex control schemes [Adamczyk'08, Gorton'06]
  - Overall lack of supporting control theory based controller
  - **Limiting their applicability**

OVERVIEW

Systematic integration of self-adaptive mechanisms into software systems through control theory centric architecture models







Generality | Visibility | Composition

1 Feedback Control Definition Language

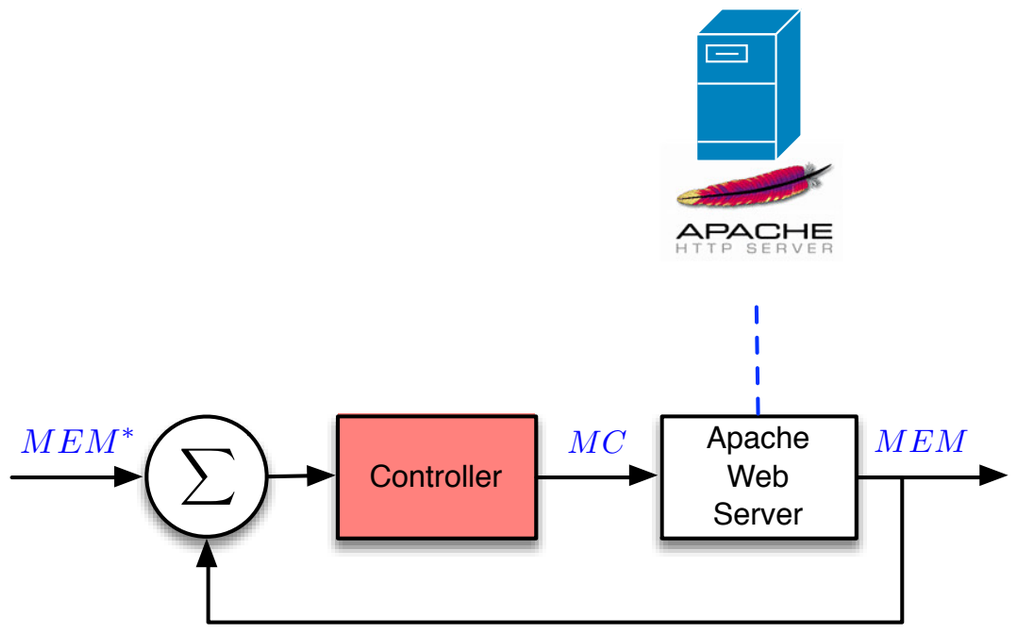
2 The ZNN.COM case study

1

Feedback Control Definition Language

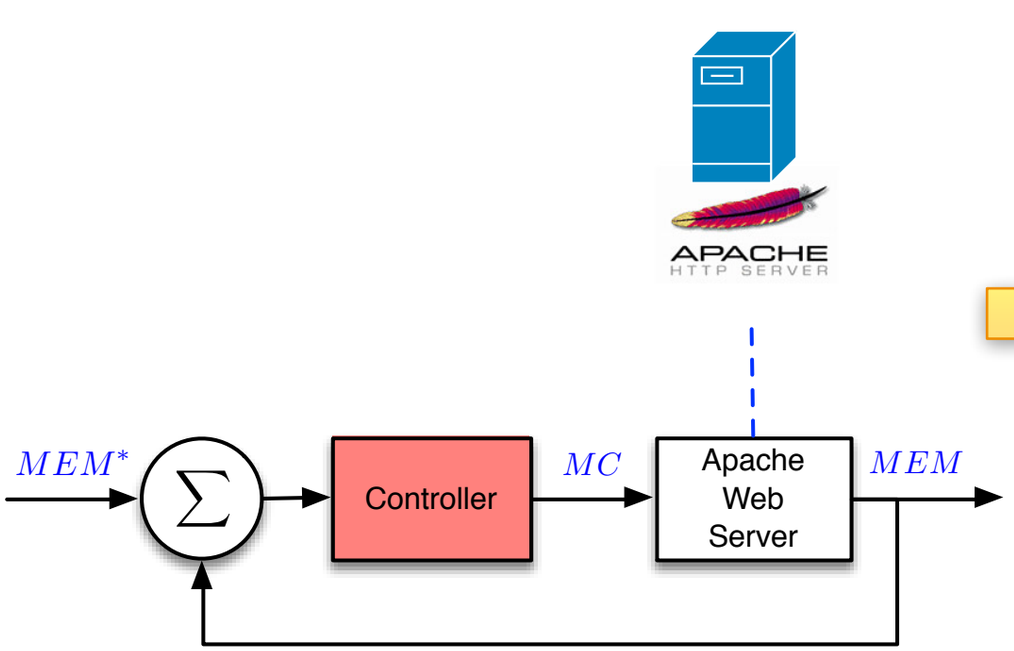
FEEDBACK CONTROL DEFINITION LANGUAGE - IN A NUTSHELL

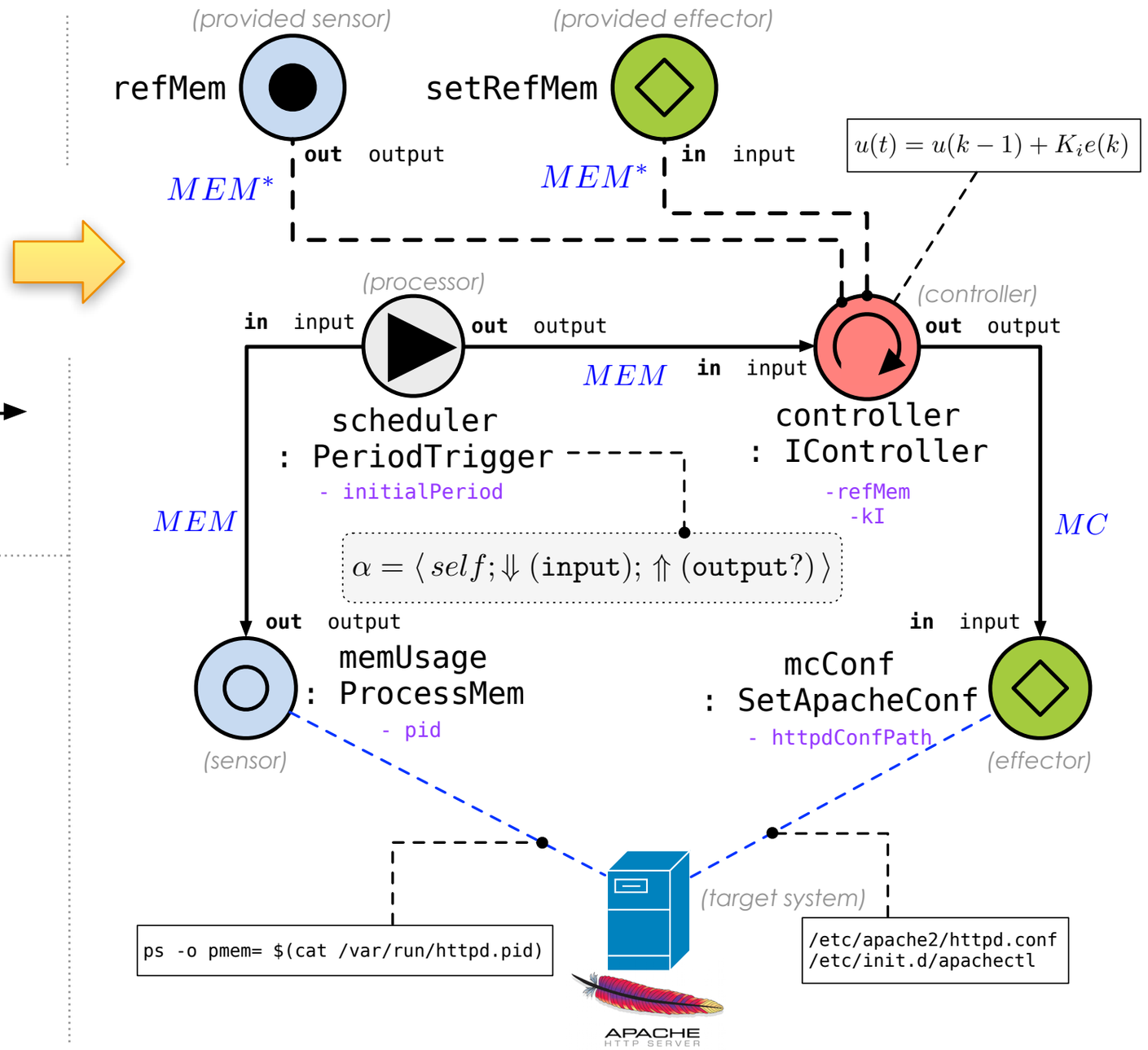
Apache adaptation example - *adjusts the maximum number of connections to be processed simultaneously (MC) based on the difference between reference (MEM*) and measured memory usage (MEM) [Hellerstain'04].*



FEEDBACK CONTROL DEFINITION LANGUAGE (FCDL) - 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'04].*





- Domain-specific modeling language
- Network of Adaptive Elements (AEs)
  - actor-like element
  - push/pull communication
  - properties
  - specifies implementations
  - supports reflection
  - defines interaction contracts

2

THE ZNN.COM CASE STUDY

THE ZNN.COM CASE STUDY

- A news service model
- Web-based N-tier client-server
- Originally used for Rainbow evaluation [Cheng'09]
- Acknowledged SEAMS case-study
- Partially used by others (e.g., DYNAMICO, Zenshin, AdaptCases)

- **Objective**
  - *"To serve the content within reasonable response time and quality in the event of traffic spikes caused by highly popular news."*

- **Challenges**
  - content adaptation (e.g. serving reduced content quality),
  - service differentiation (e.g. prioritizing premium customers),
  - infrastructure adaptation (e.g. adapting the size of the server pool)

http://www.hpi.uni-potsdam.de/giese/public/selfadapt/exemplars/model-problem-znn-com/

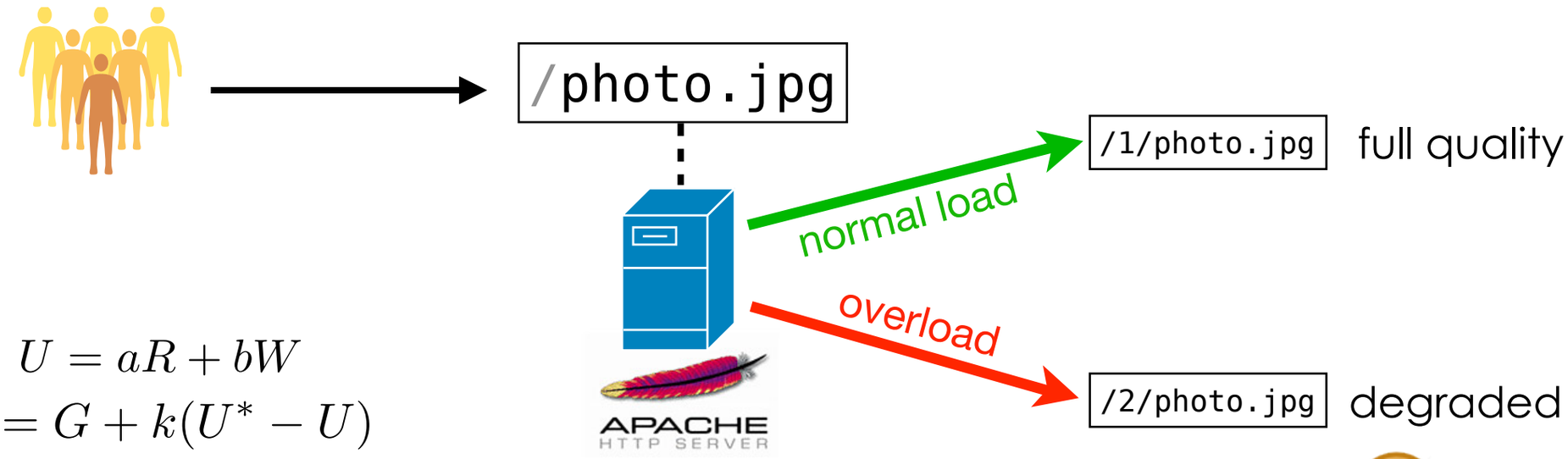
ZNN.COM - LOCAL CONTENT DELIVERY ADAPTATION

QoS management control of web servers by content delivery adaptation

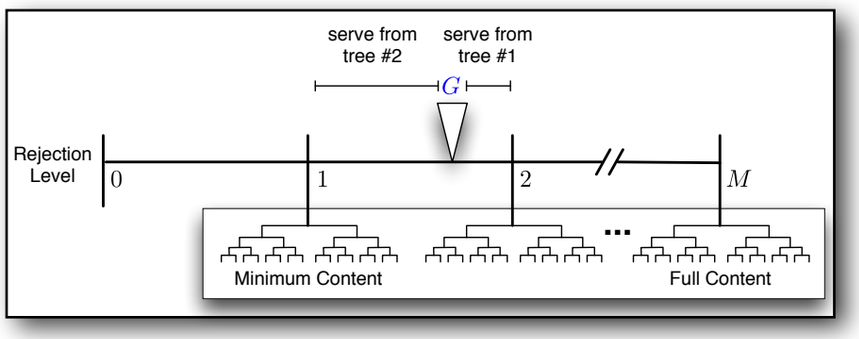
Goal: maintain server load around some pre-set value

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

Prerequisite: preprocessed content (different quality and size)



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



[Abdelzaher et al., 1999, 2002]

Using FCDL

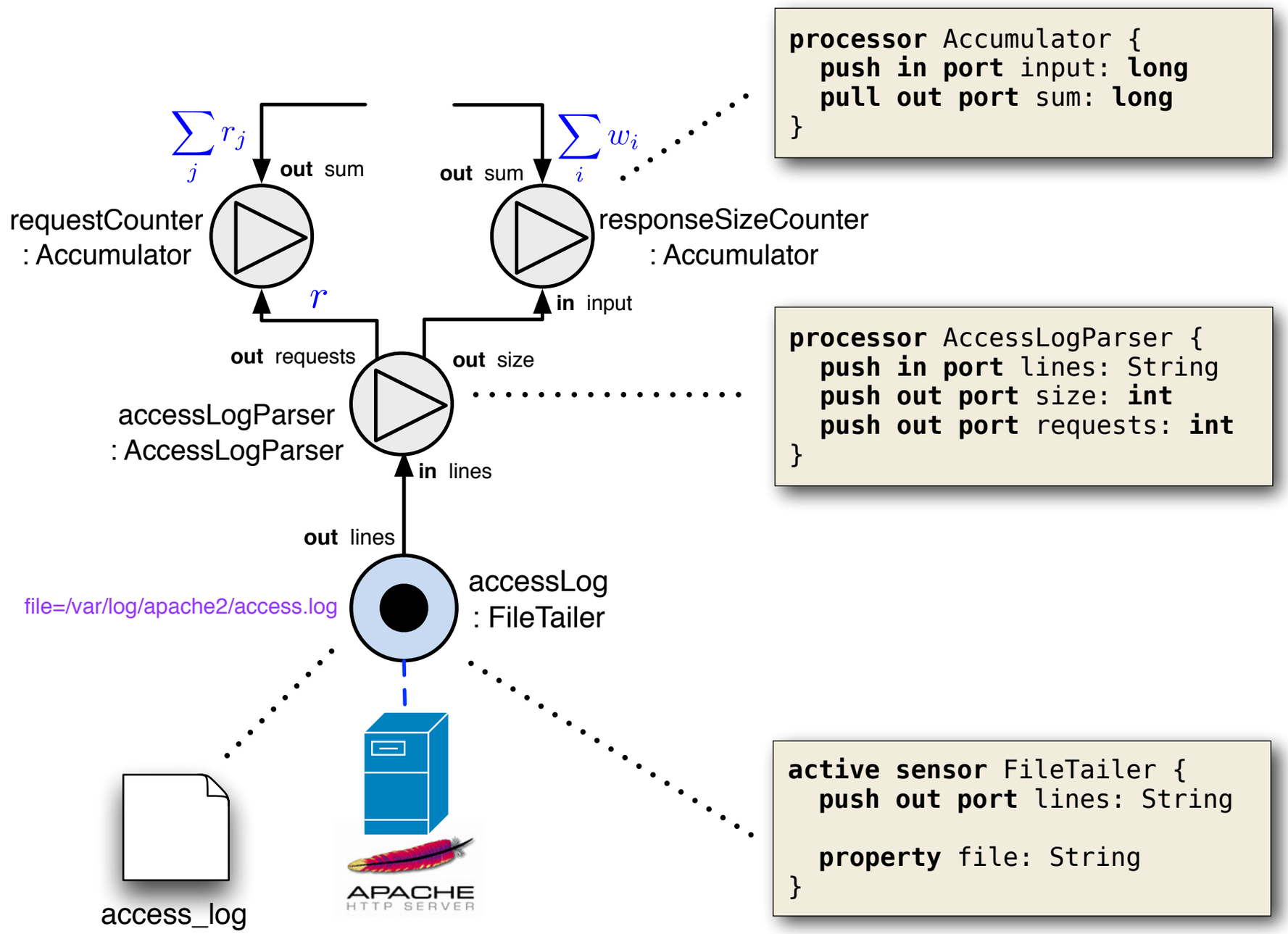
Generality | Visibility | Composition

ZNN.COM - LOCAL CONTENT DELIVERY ADAPTATION

1. Compute the number of requests (r) and size of responses (w)
2. Compute the requests rate (R), bandwidth (W) and utilization (U)
3. Compute severity of adaptation (G)

ZNN.COM - LOCAL CONTENT DELIVERY ADAPTATION

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




```
processor Accumulator {
  push in port input: long
  pull out port sum: long
}
```

```
processor AccessLogParser {
  push in port lines: String
  push out port size: int
  push out port requests: int
}
```

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

  property file: String
}
```

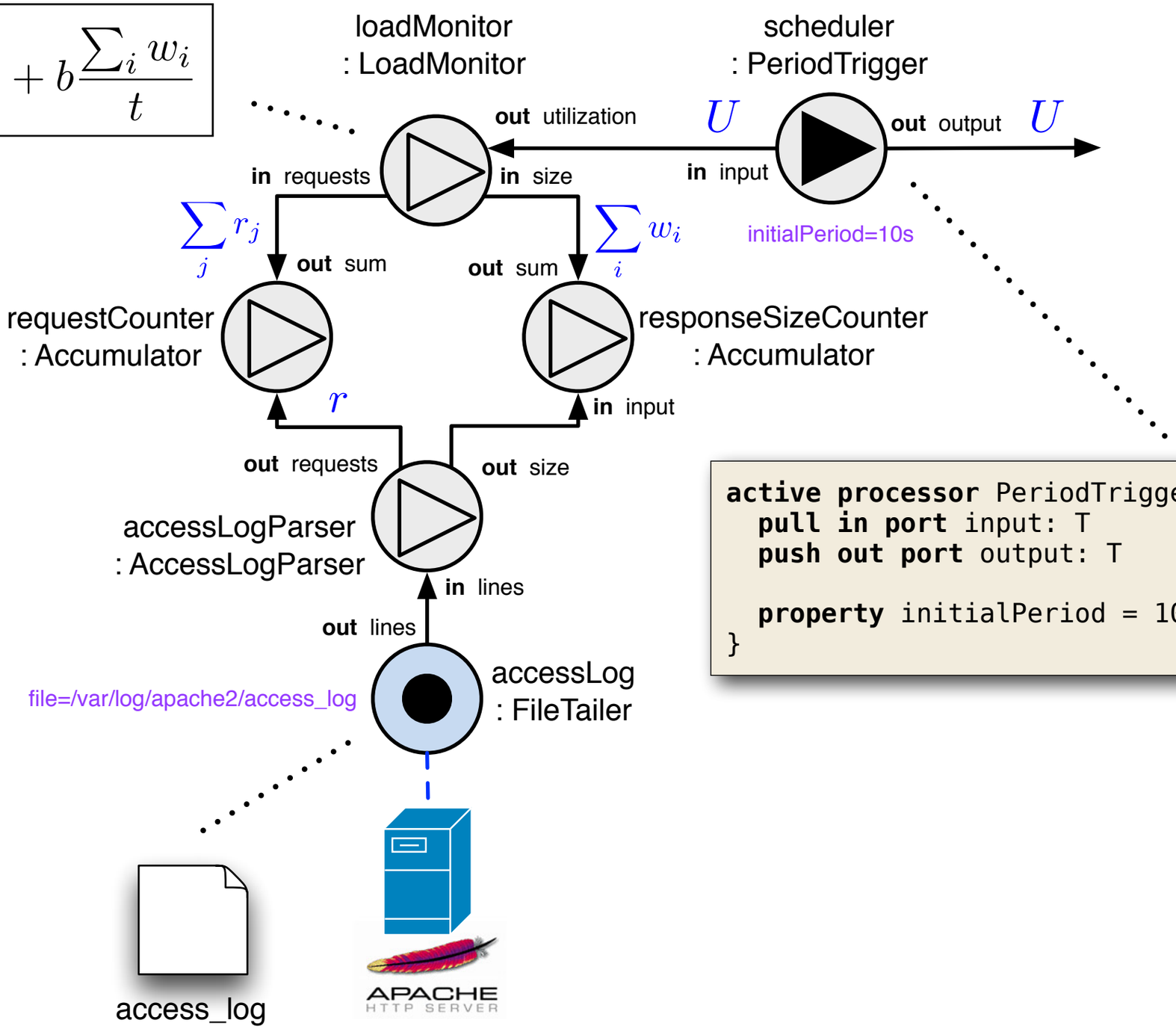
Generality

Visibility

ZNN.COM - LOCAL CONTENT DELIVERY ADAPTATION

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

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



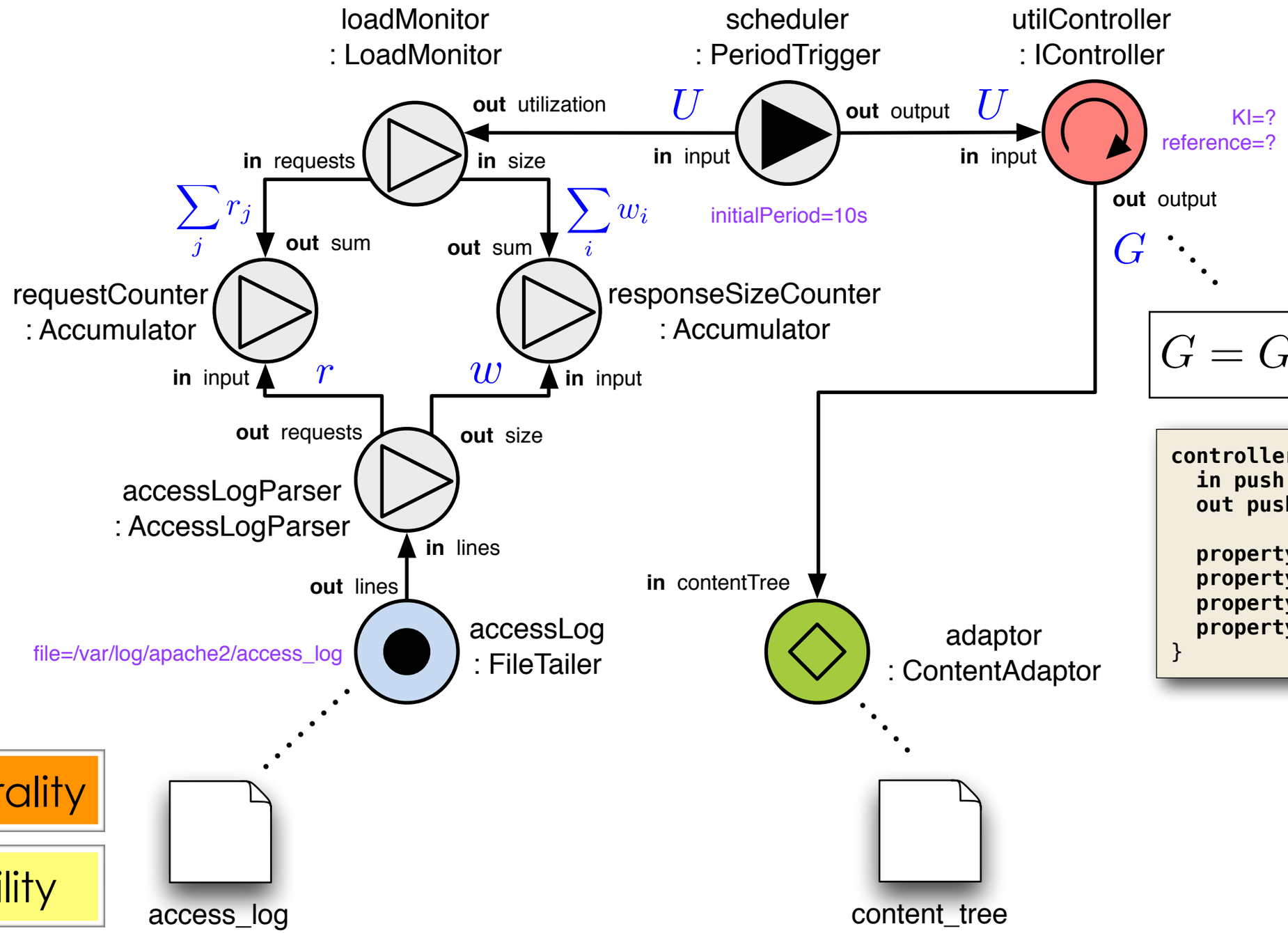

```
active processor PeriodTrigger<T> {
  pull in port input: T
  push out port output: T

  property initialPeriod = 10.seconds
}
```

Generality

Visibility

ZNN.COM - LOCAL CONTENT DELIVERY ADAPTATION

3 Compute severity of adaptation (G)



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

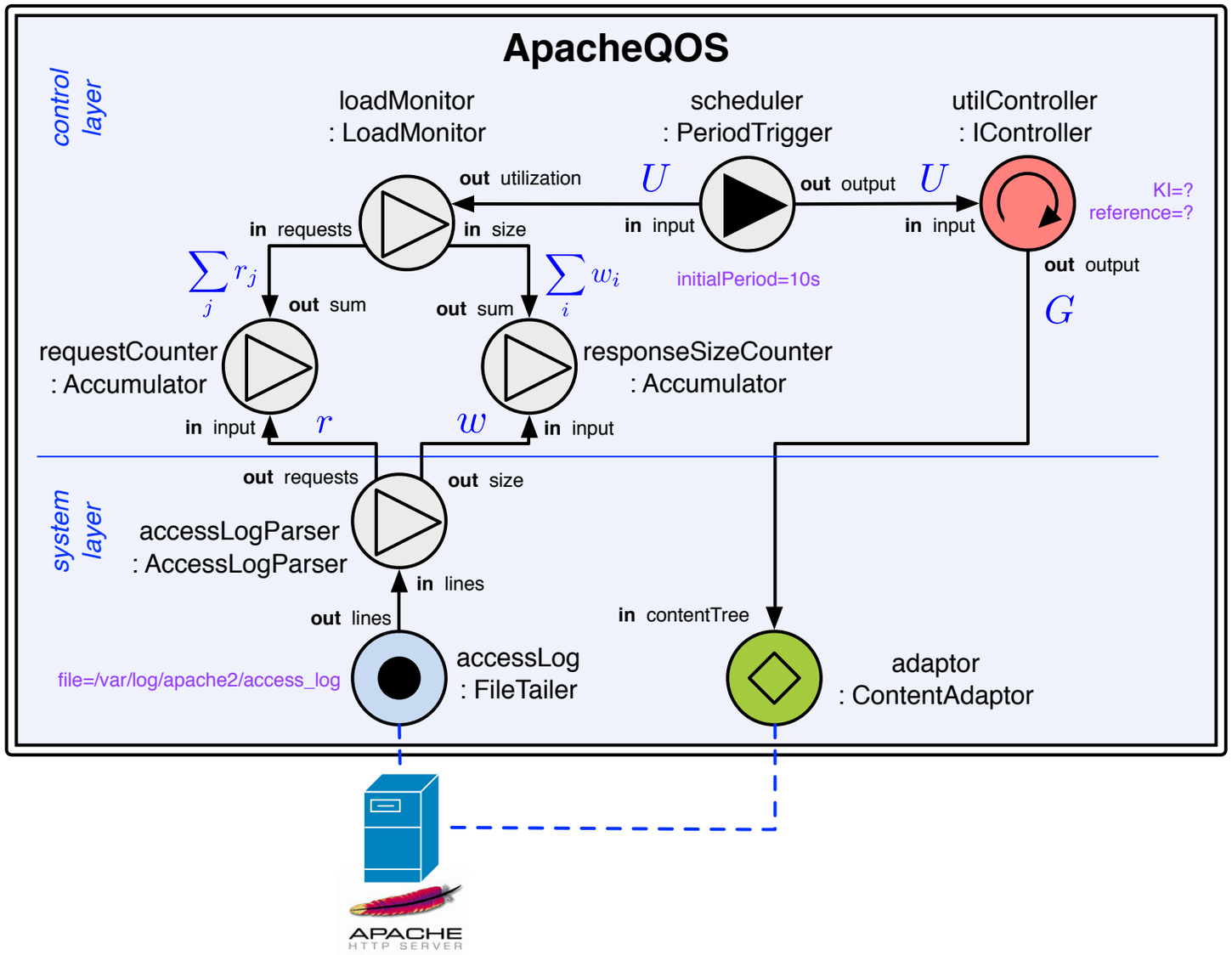
```
controller IController {
  in push port input: double
  out push port output: double

  property KI: double
  property reference: double
  property loBnd: double
  property upBnd: double
}
```

Generality

Visibility

ZNN.COM - LOCAL CONTENT DELIVERY ADAPTATION

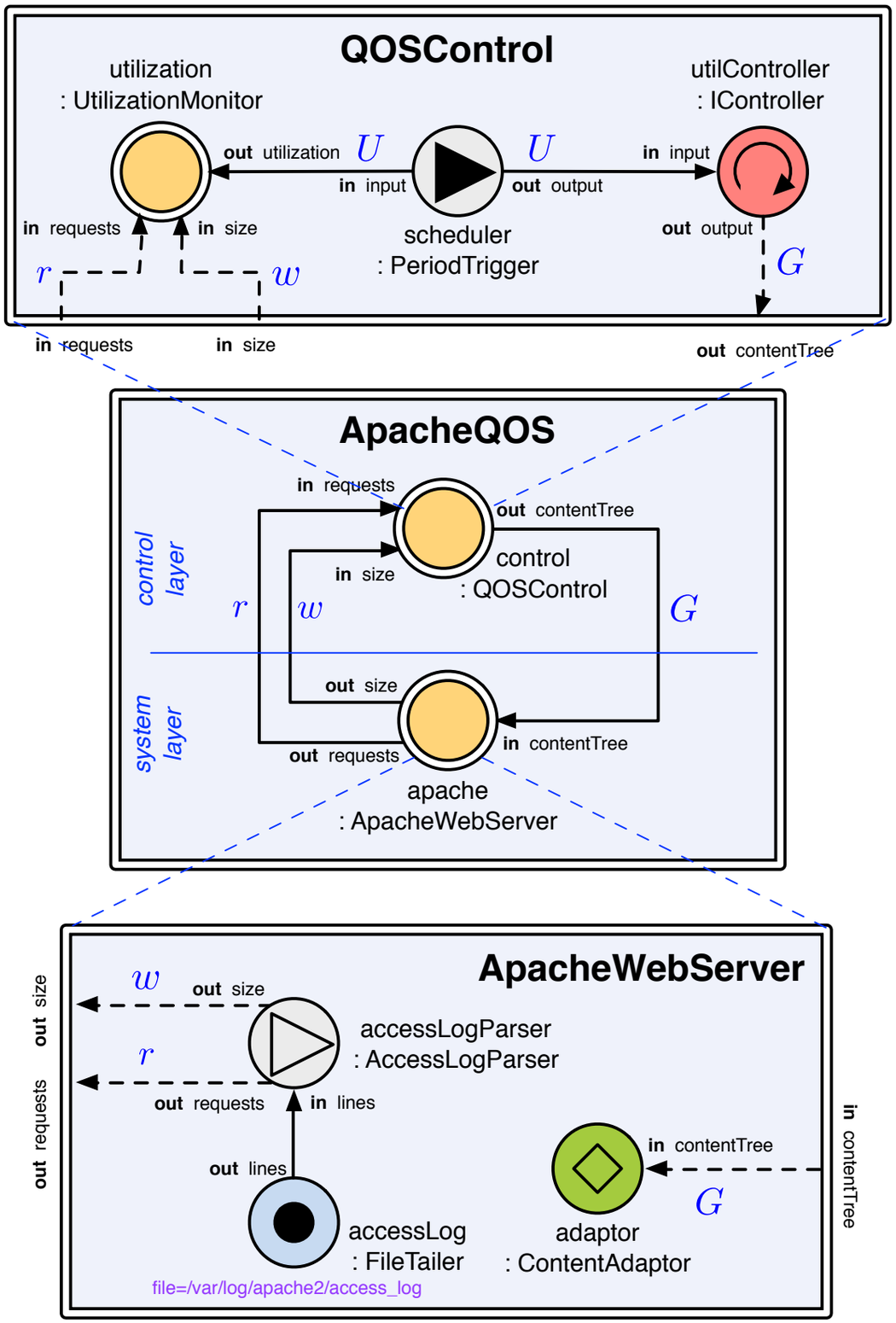
Complete model




```
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

}
```

Generality | Visibility | Composition

ZNN.COM - LOCAL CONTENT DELIVERY ADAPTATION



Composition

Visibility

Generality

ZNN.COM - ADAPTIVE CONTROL

- Using the reflection support for adaptive control

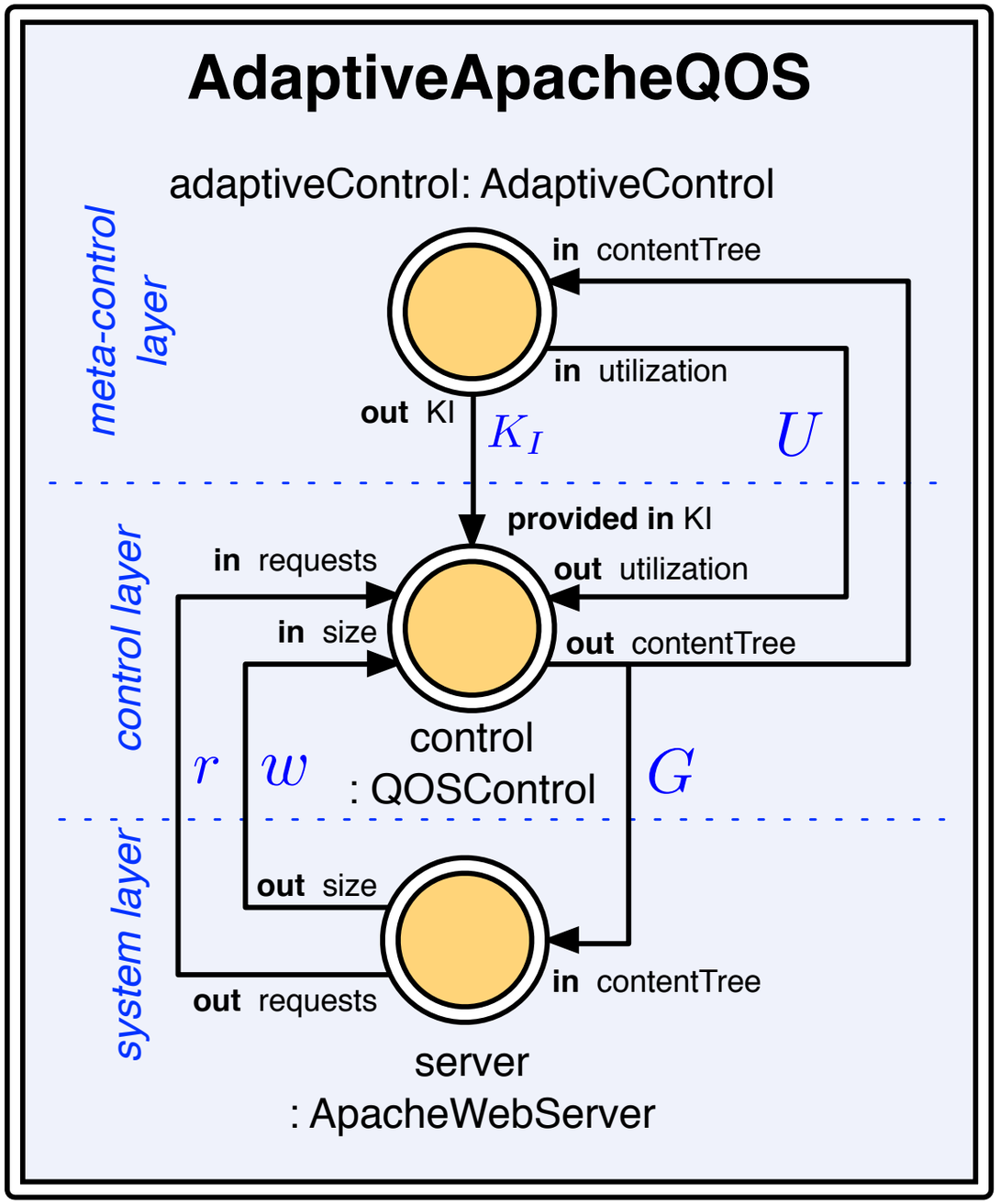
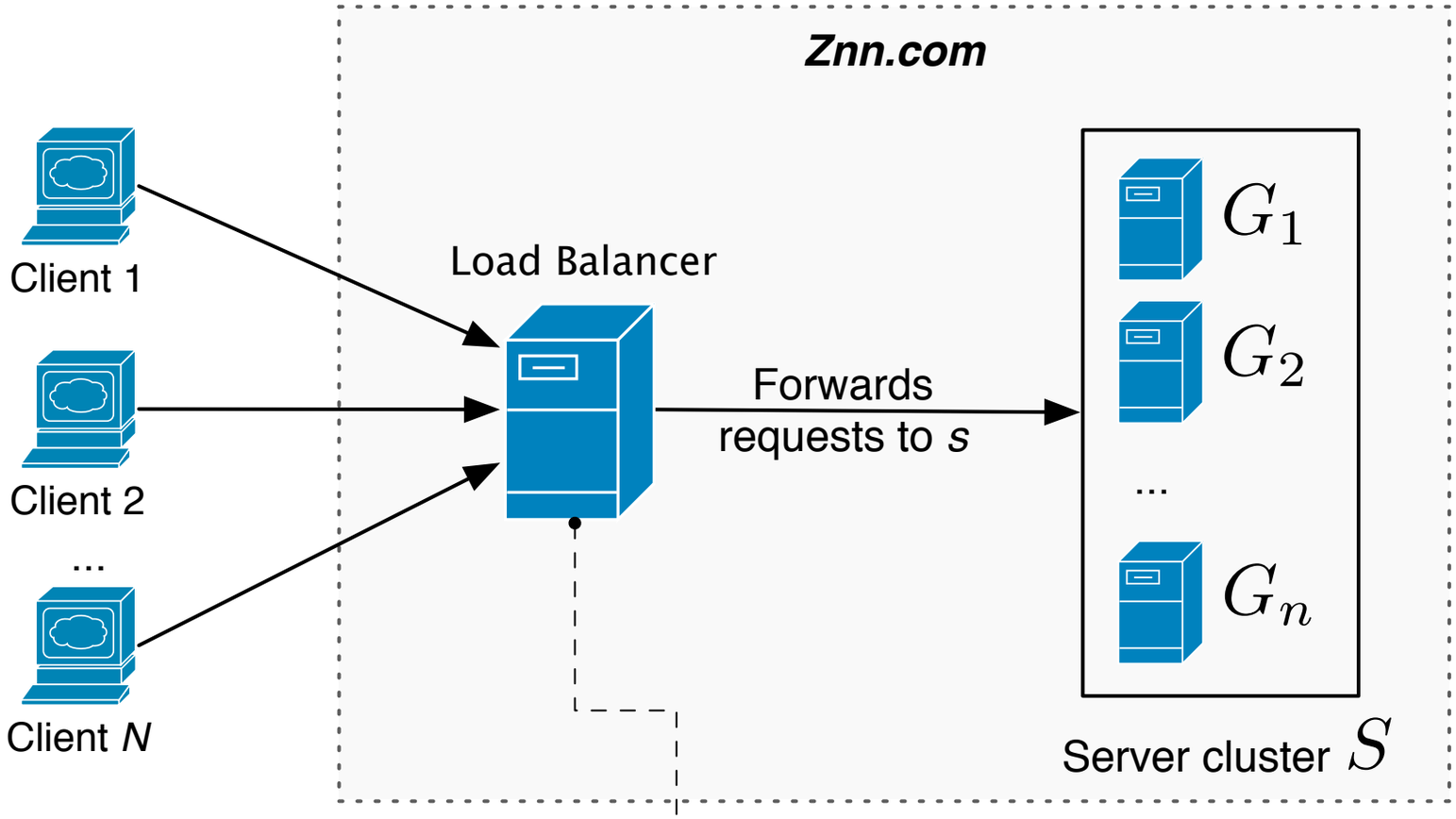


ILLUSTRATION - DISTRIBUTED CONTENT DELIVERY ADAPTATION

- QoS management control of a pool of web servers using content delivery adaptation.
- Load balancer schedules requests to a server with highest QoS.



$$s \in S \text{ such that } G_s = \max(G_1, \ldots, G_n)$$

ILLUSTRATION - DISTRIBUTED CONTENT DELIVERY ADAPTATION

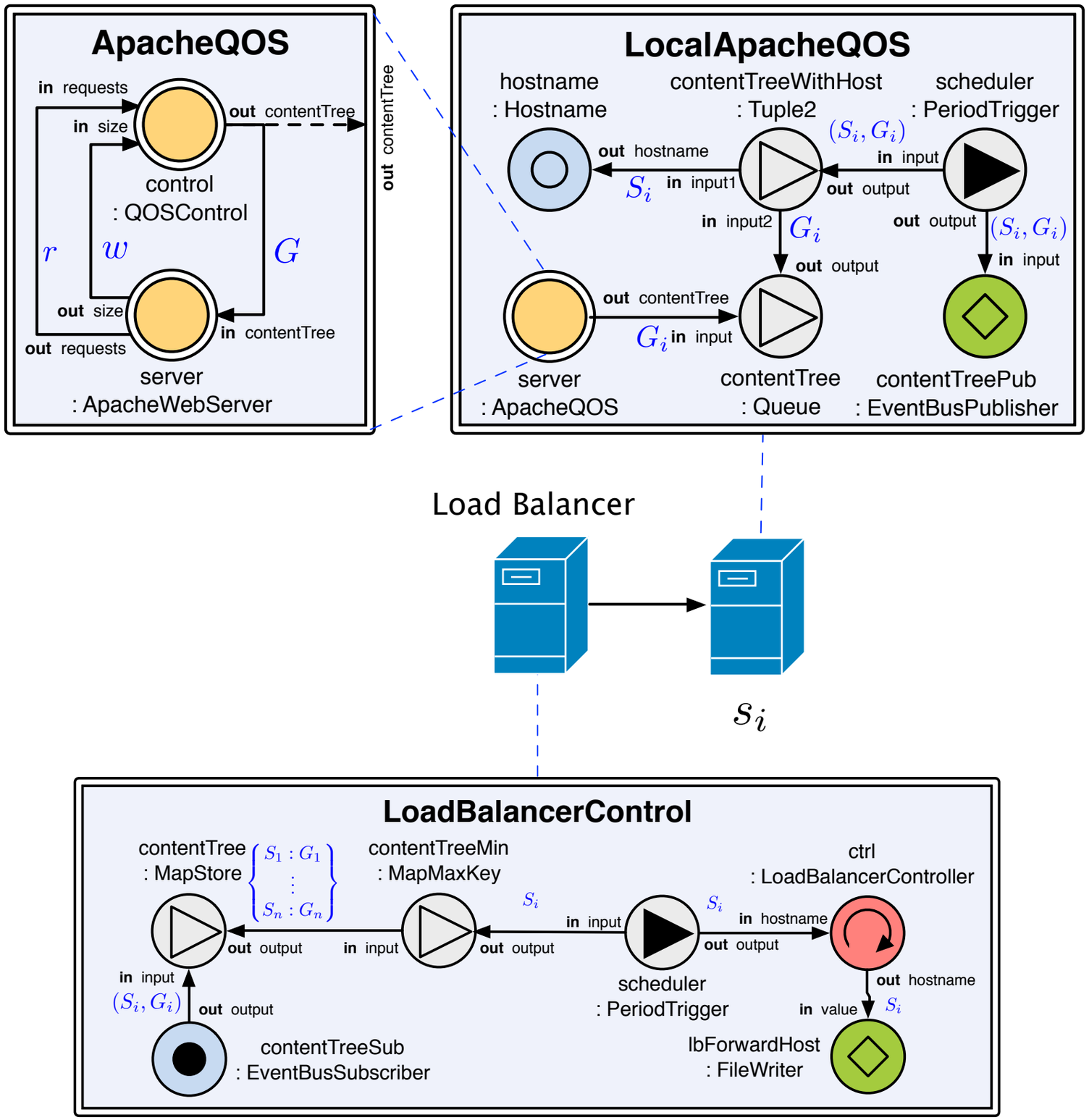
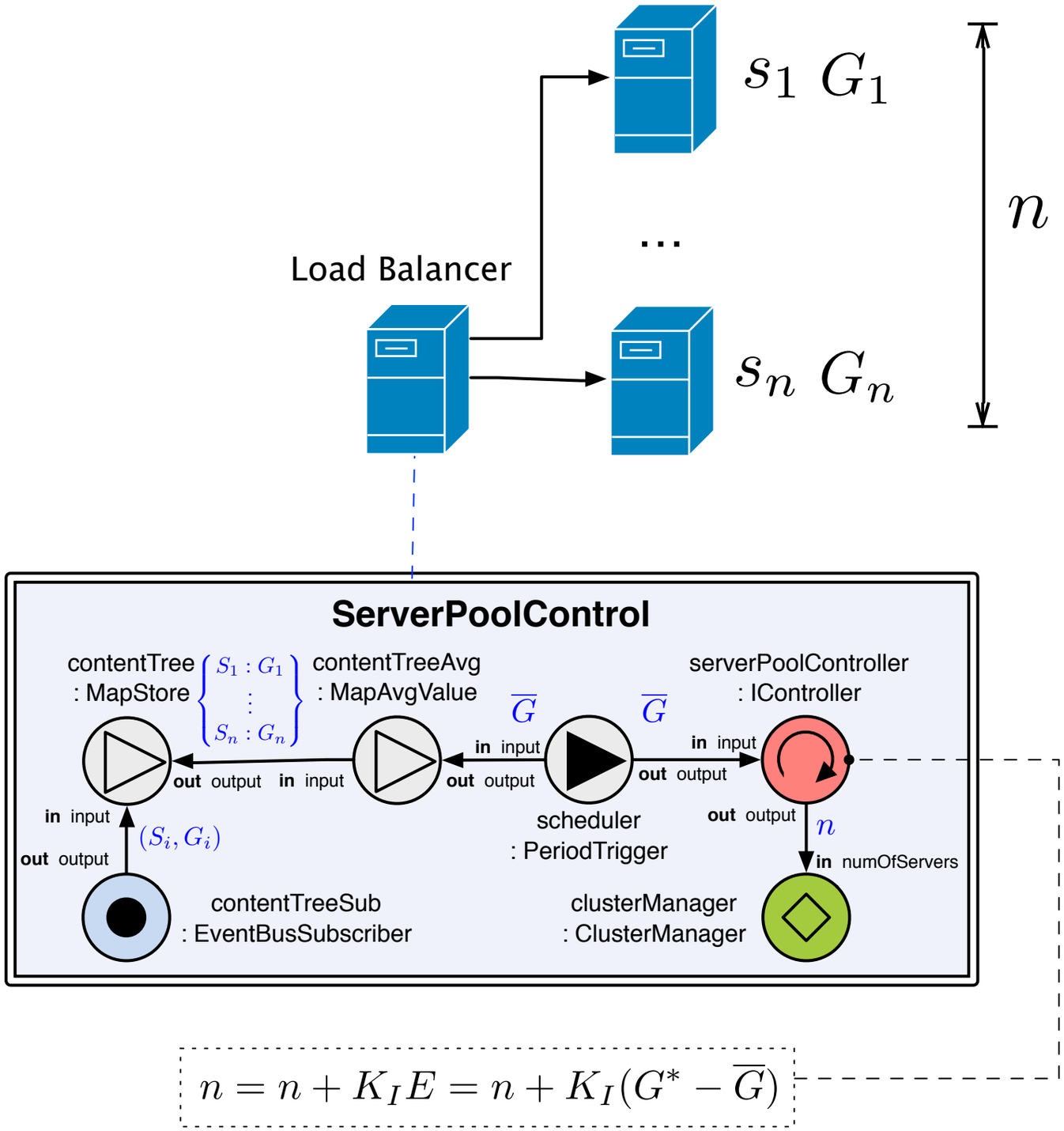
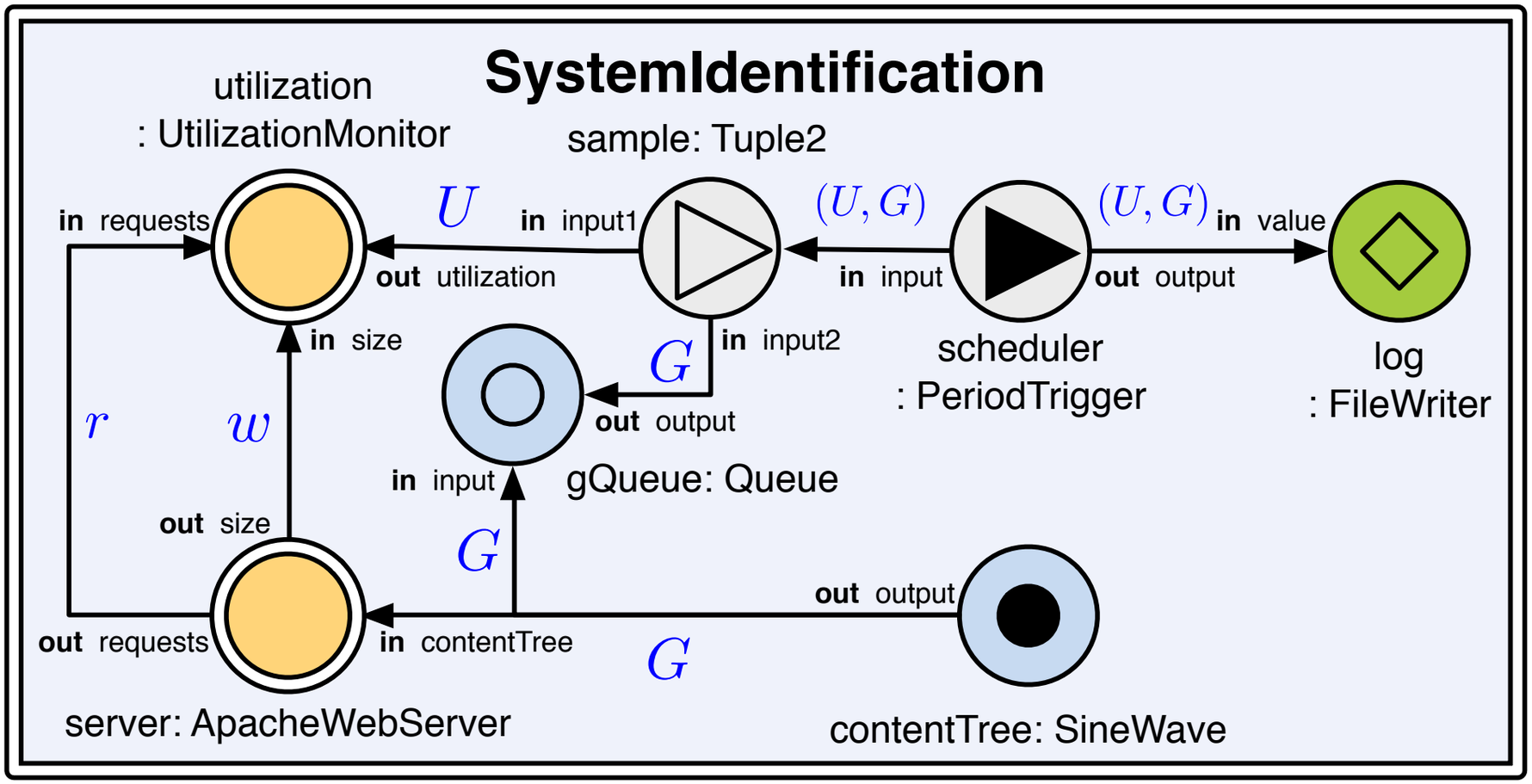


ILLUSTRATION - RESOURCE MANAGEMENT



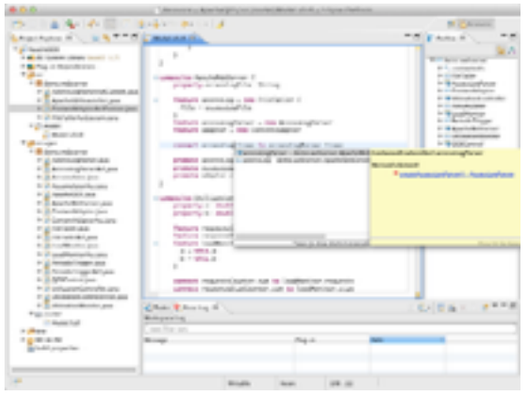
ZNN.COM - SYSTEM IDENTIFICATION

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

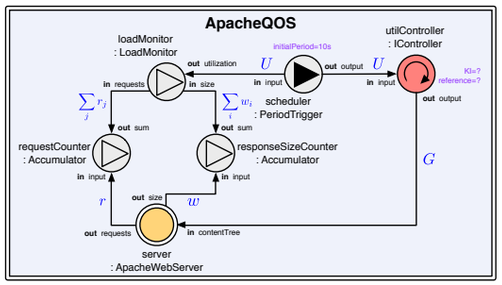


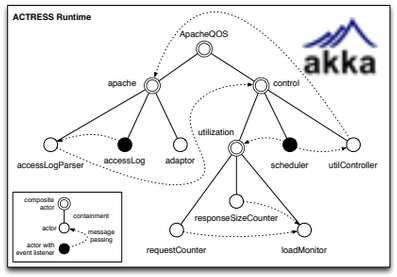
IMPLEMENTATION

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

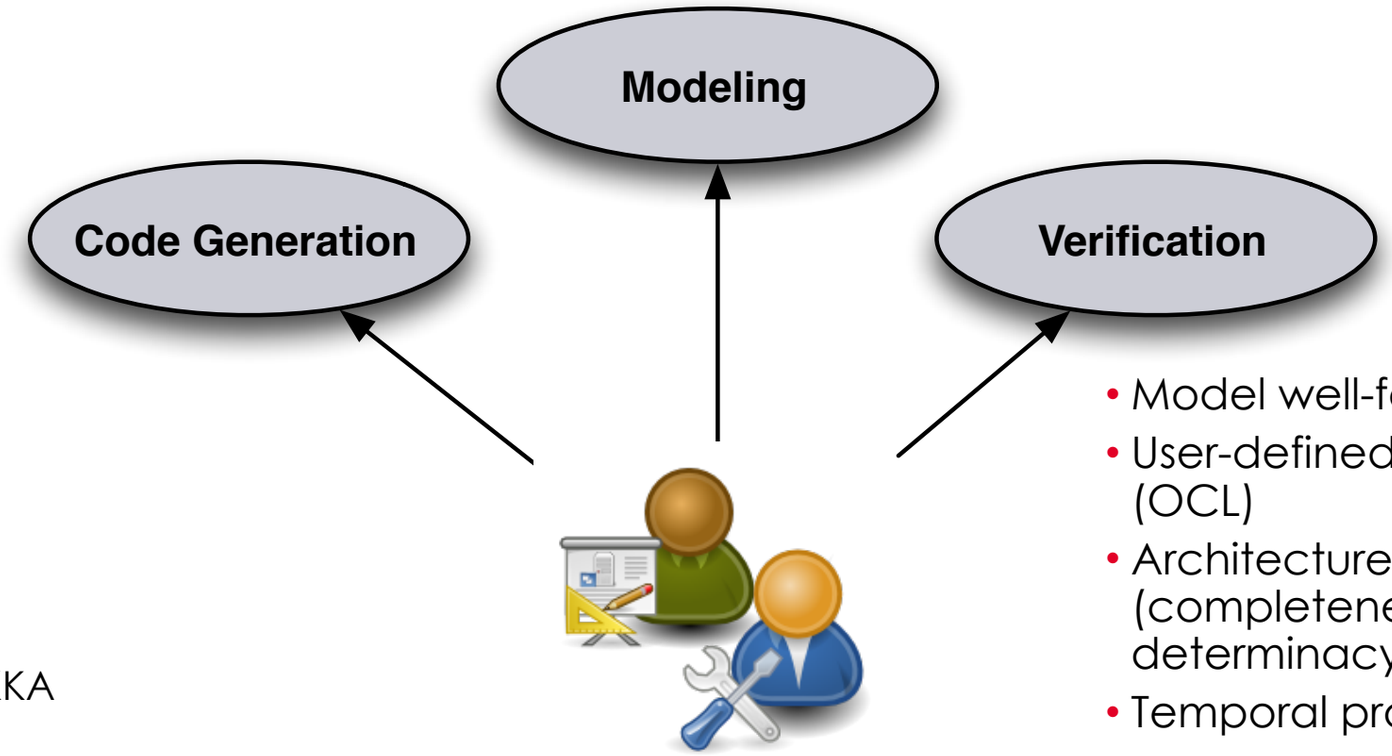


- xFCDL (Extended FCDL)
  - Textual DSL for authoring FCDL models
  - Modularity, Java interoperability, Xbase
  - Eclipse IDE support





- ACTRESS runtime
  - based on Java/AKKA



- Model well-formedness
- User-defined structural constraints (OCL)
- Architecture verification (completeness, consistency, determinacy)
- Temporal properties (PROMELA/SPIN)

3

Conclusions

SUMMARY

- Combining self-adaptive software systems with principles of MDE to provide **systematic** and **tooled approach** for **integrating control mechanisms** into **software systems**.
- A proof of concept implementation and **tools facilitating** the language use including **modeling**, **code synthesis** and **verification** support.

FUTURE WORK

- Address ACTRESS limitations - a new MPS-based implementation
- More robust FCDL - support data units, input output assertions
- ZNN.COM challenge
  - From a case study to a benchmark
  - Easily reusable (docker packaging)
  - INRIA Lille Non-A team in charge of a new controller
  - Evaluation agains two base lines
    - Apache mod_proxy
    - Amazon elastic load balancer

Thank you

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