Abstractions for Distributed Systems
Workshop associated to EuroPar 2008

Behavioural skeletons: a programming abstraction relieving programmers of non functional concerns

Marco Danelutto

Dept. Computer Science, Univ. of Pisa, Italy &
Programming model Institute, CoreGRID

Outline

- ★ Characterization of distributed architectures
- ★ Behavioural skeletons
- ★ Applications
- ★ Experimental results
- ★ Ongoing work
- ★ Conclusions

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Distributed architectures: features of interest

★ heterogeneity

- computing resources, interconnection network

★ dinamicity

- node/network faults, non exclusive resource access

★ non negligible communication cost

- communications, access to logically shared data

Cloud perspective ...

★ cluster of clusters

- heterogeneous interconnection structure

★ successive upgrades/maintenance

- heterogeneous resources

★ non exclusive usage

- dynamic resource availability

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Behavioural skeleton

★ Programming abstraction (programming model)

★ Combine “existing” knowledge/technology

- algorithmic skeletons & autonomic computing
- parallelism exploitation & non functional features management

★ Raise the level of abstraction provide to the final user/ programmer

★ Hide more and more details/programming efforts in RTS

The concept

The concept

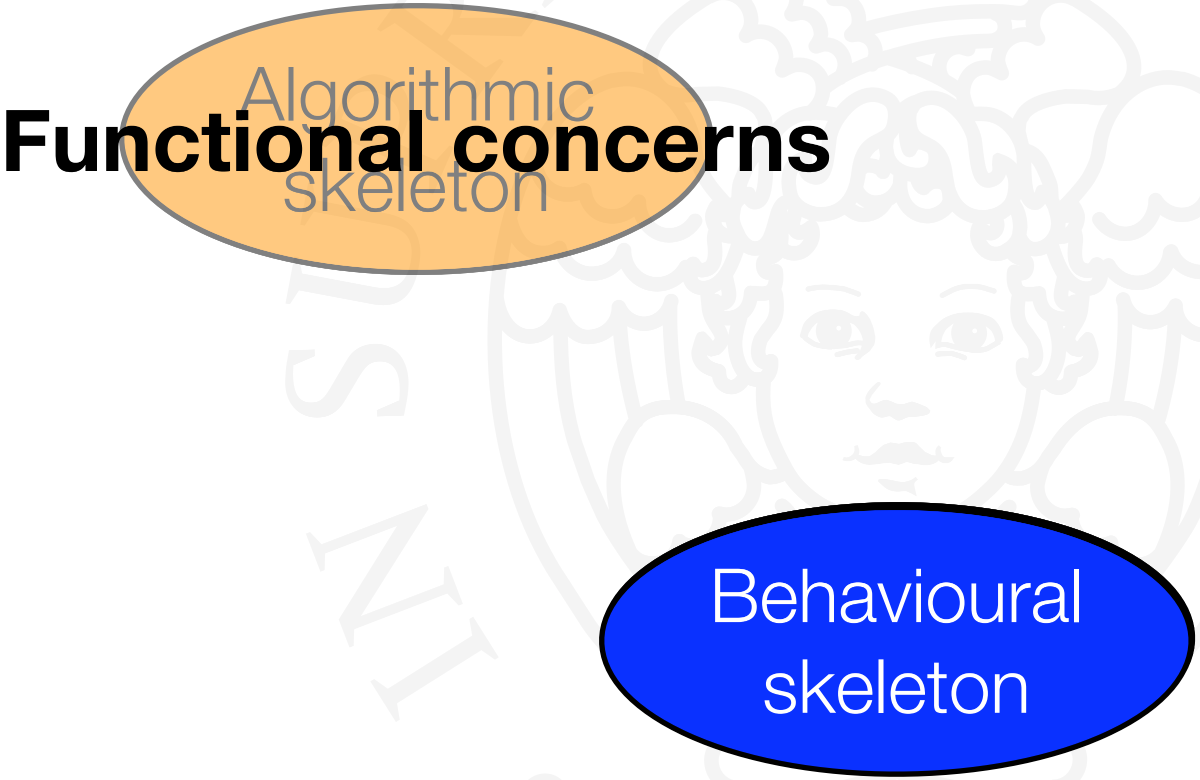
Algorithmic skeleton

Autonomic manager

The concept

Behavioural skeleton

The concept

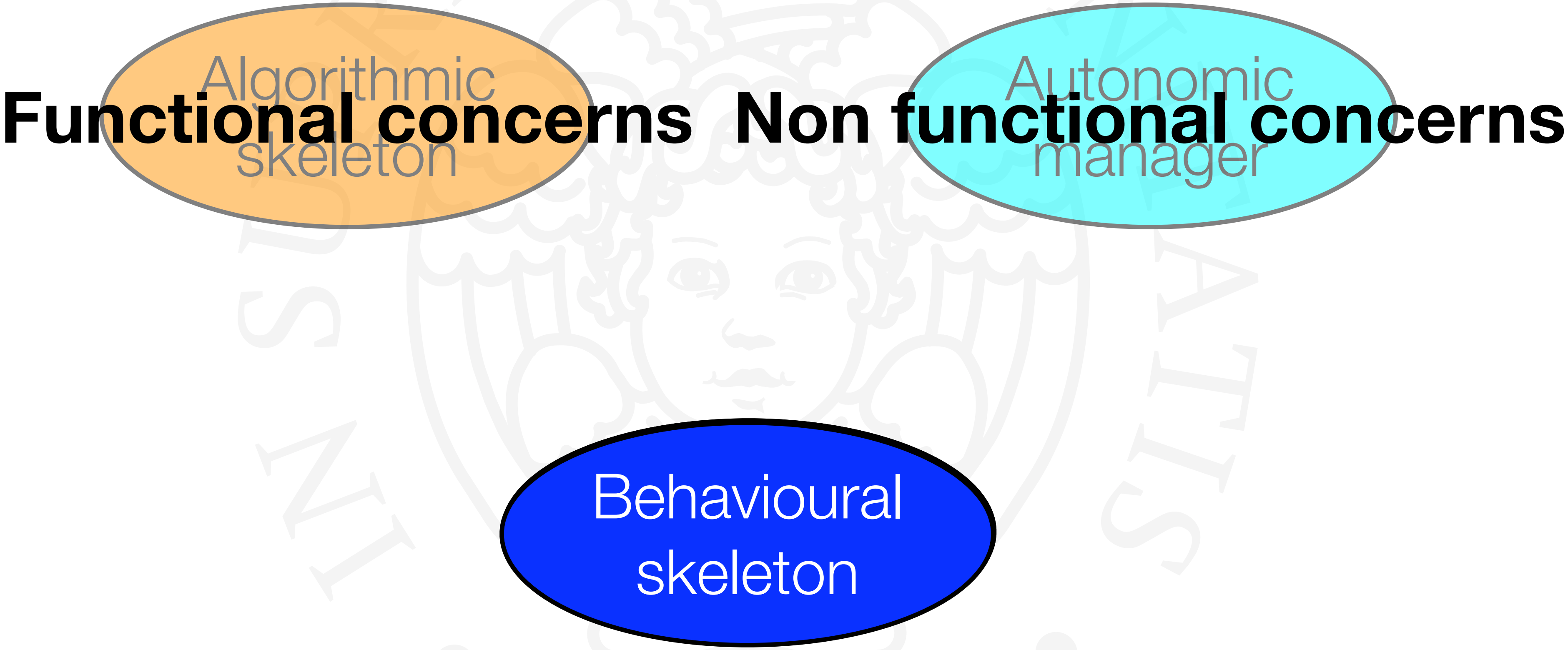


Algorithmic skeleton

Functional concerns

Behavioural skeleton

The concept



Algorithmic skeleton

Functional concerns

Autonomic manager

Non functional concerns

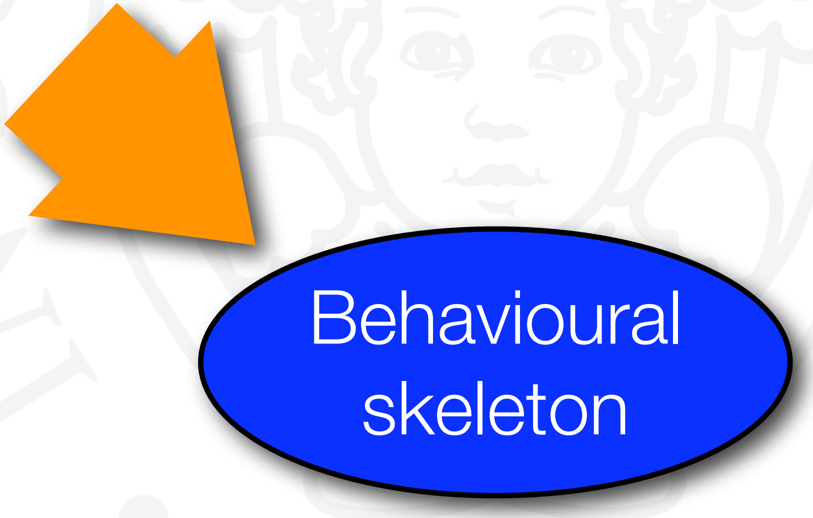
Behavioural skeleton

The concept

Behavioural skeleton

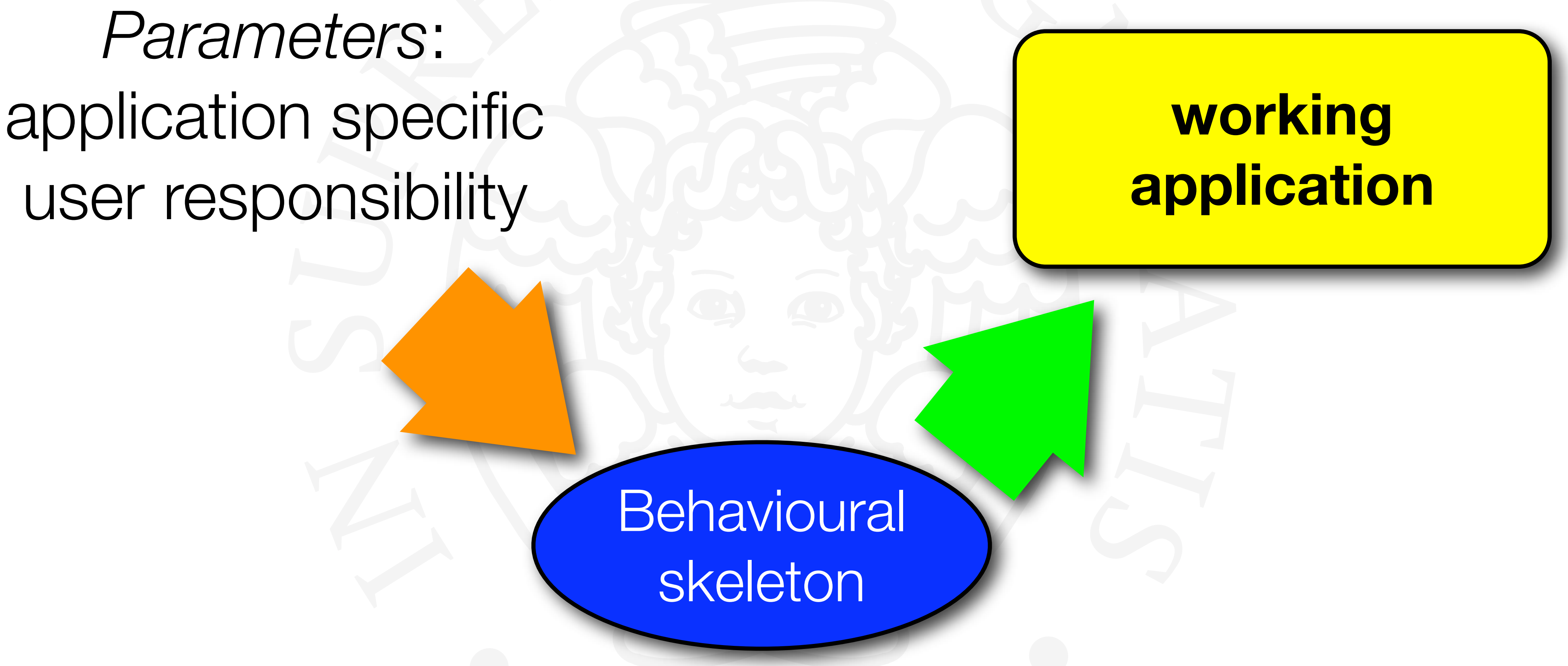
The concept

Parameters:
application specific
user responsibility



Behavioural skeleton

The concept



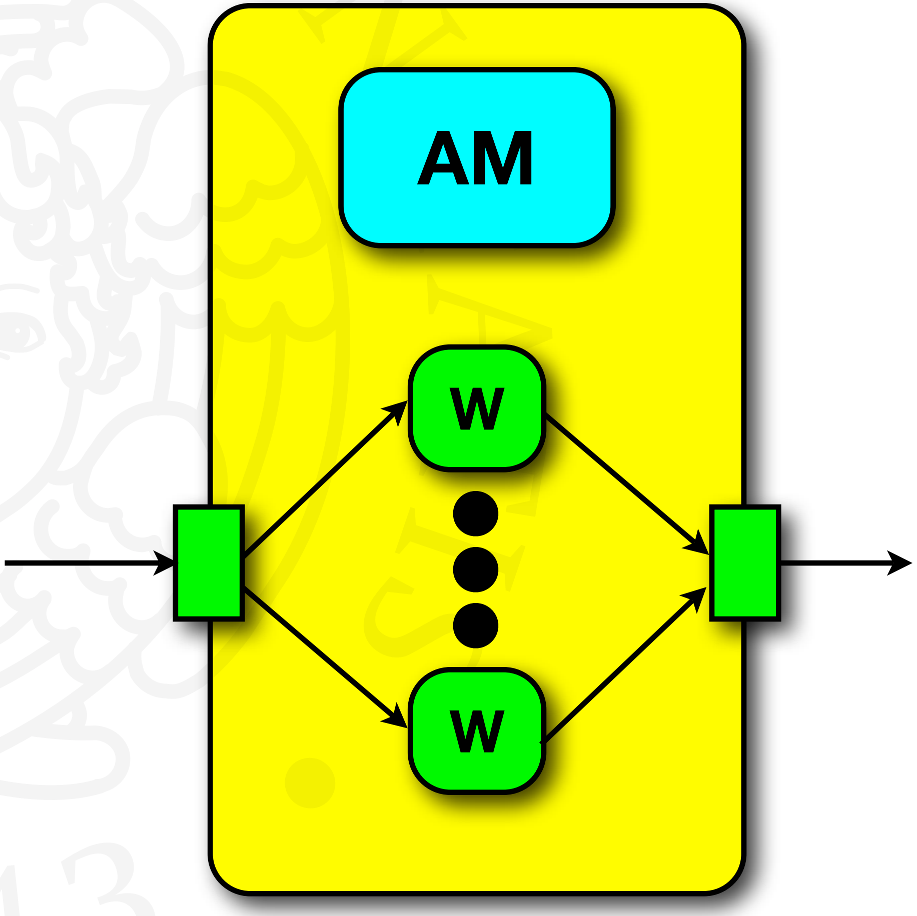
Parameters:
application specific
user responsibility

Behavioural skeleton

working application

Behavioural skeleton sample: task farm

- ★ Functional part: compute embarrassingly parallel application
  - parameters: function to be computed on each input item (task)
- ★ Non functional part: guarantee (best effort) a user supplied performance contract
  - in presence of faults, with dynamic and heterogeneous resources



AM: autonomic manager

★ Implements classical autonomic cycle

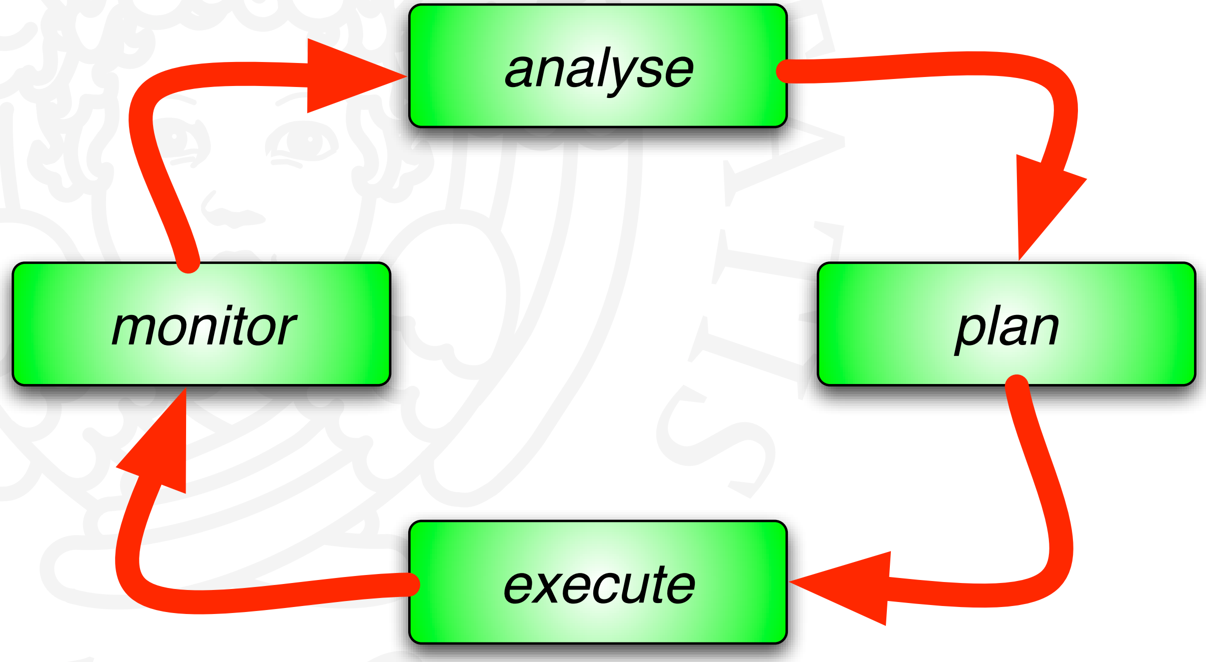
(a) monitor current status

(b) look up for actions

(c) plan execution

(d) execute actions

(e) repeat



Sample autonomic management

★ In case of fault of Wi:

- lookup for new resource, instantiate new worker

★ Performance non compliant to user contract

- if not bound by inter-arrival time and/or communication latencies
  - add new worker, or
  - move slower worker to faster resources, if available

Sample autonomic management

★ Sensible programming effort required without BS:

- monitoring tools, analyse and planning capabilities, execution mechanisms
- code intermingled with functional code
- deep dependency on the parallelism exploitation pattern
    - if recongnized *could be reused* (but for intermingled functional code!)

Kind of autonomic management

★ Reactive:

- react to events (with the risk to be late)
  - rule triggering on monitoring events

★ Proactive

- anticipate decisions in such a way the future behaviour of system may be influenced by proper actions (with the risk to be early)
  - rule triggering on monitoring events AND predicates on historical data

★ Actually relies on system programmer ability to define proper rules ...

Different rôles in autonomic management cycle

★ Passive rôle

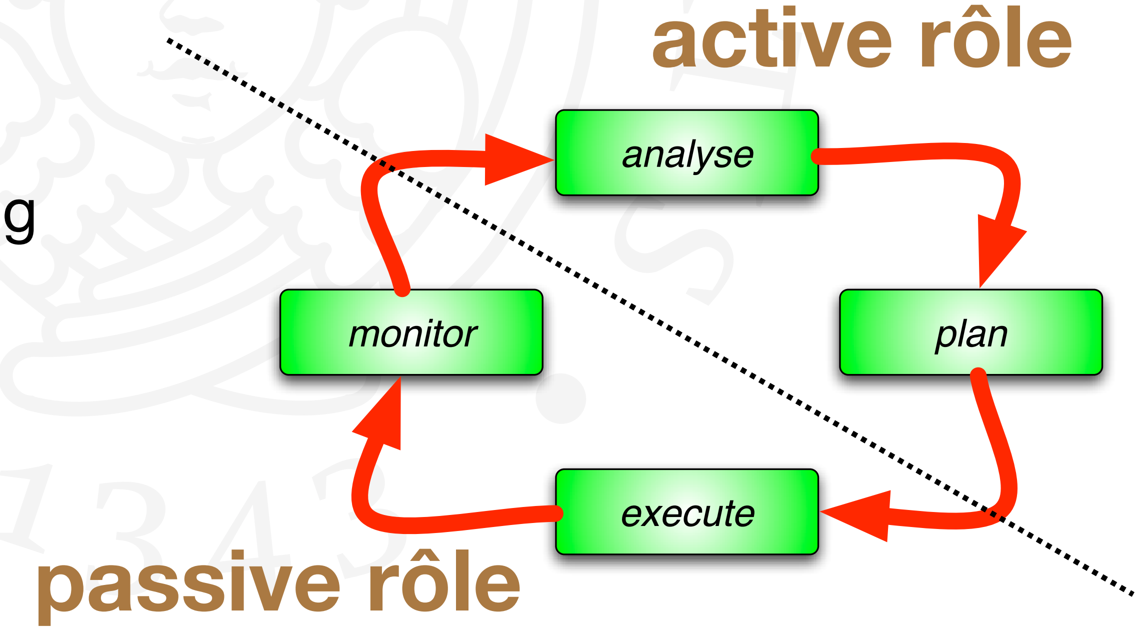
- provide mechanisms: monitoring, actuation

★ Active rôle

- provide decision tools: analysis, action planning

★ Both are of interests

- with different features



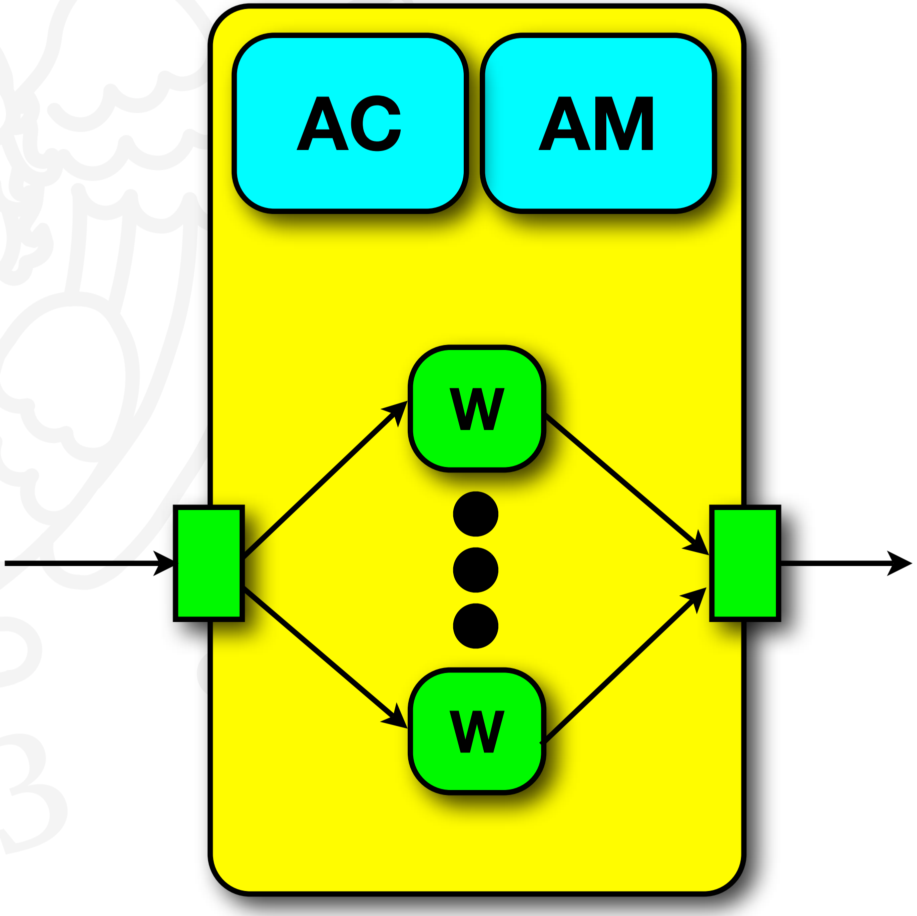
Specialization of autonomic management

★ Active part: AM the Autonomic Manager

- analyses monitored data (computation status)
- takes decisions by applying known (or learned) policies

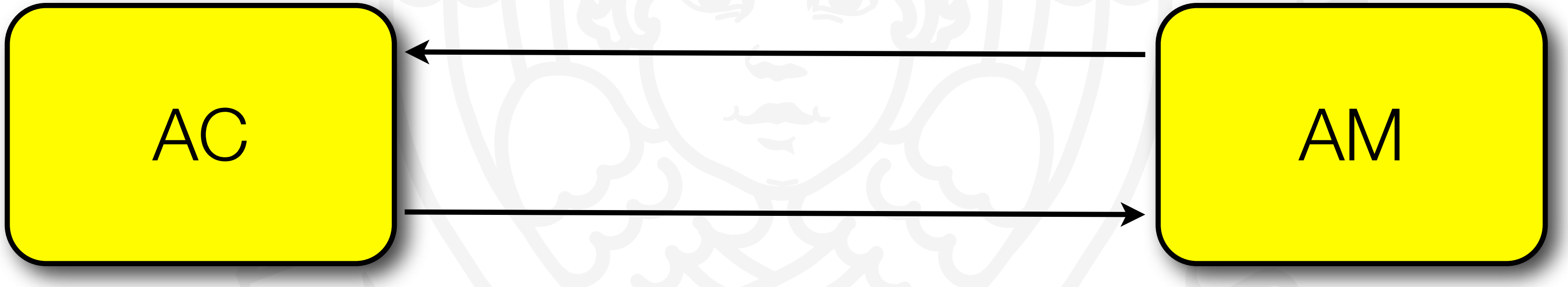
★ Passive part: AC the Autonomic Controller

- provides mechanisms to monitor computation and actuate actions



Specialization of autonomic management

queries measures
orders actions

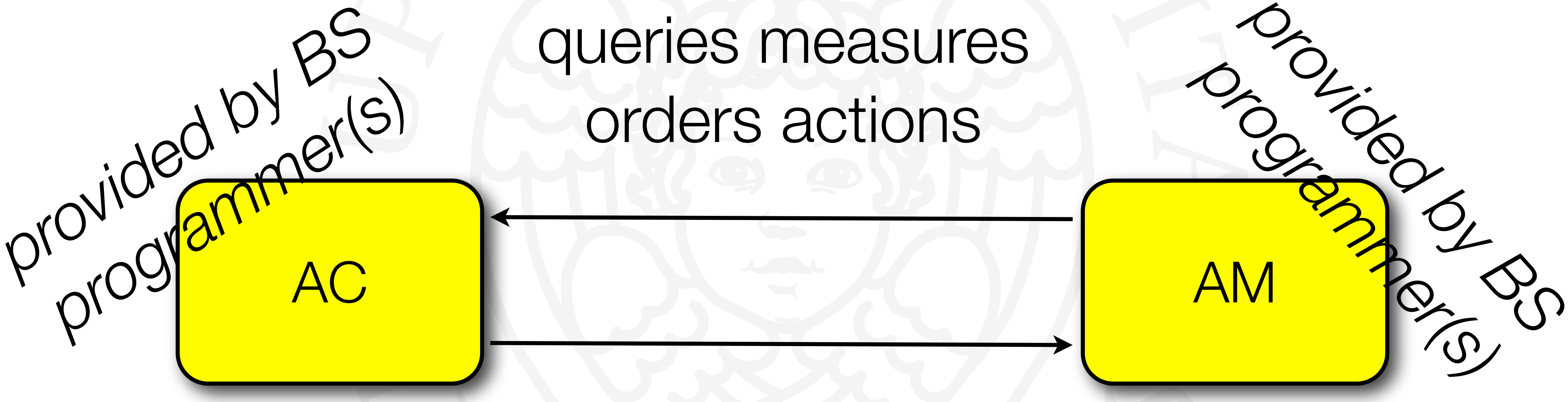


AC

AM

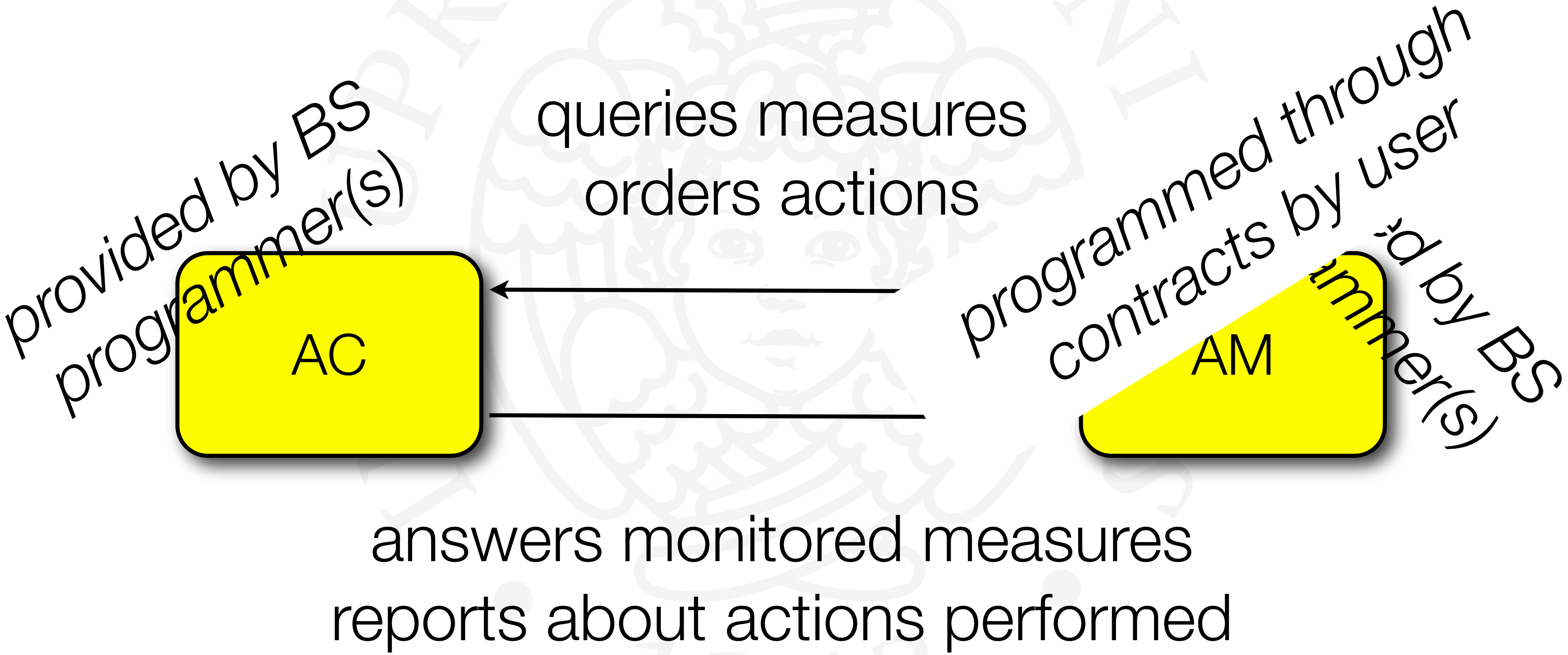
answers monitored measures
reports about actions performed

Specialization of autonomic management



answers monitored measures
reports about actions performed

Specialization of autonomic management


provided by BS programmer(s)
AC
queries measures
orders actions
programmed through contracts by user
d by BS
mmer(s)
AM
answers monitored measures
reports about actions performed

Going further ...

★ AM

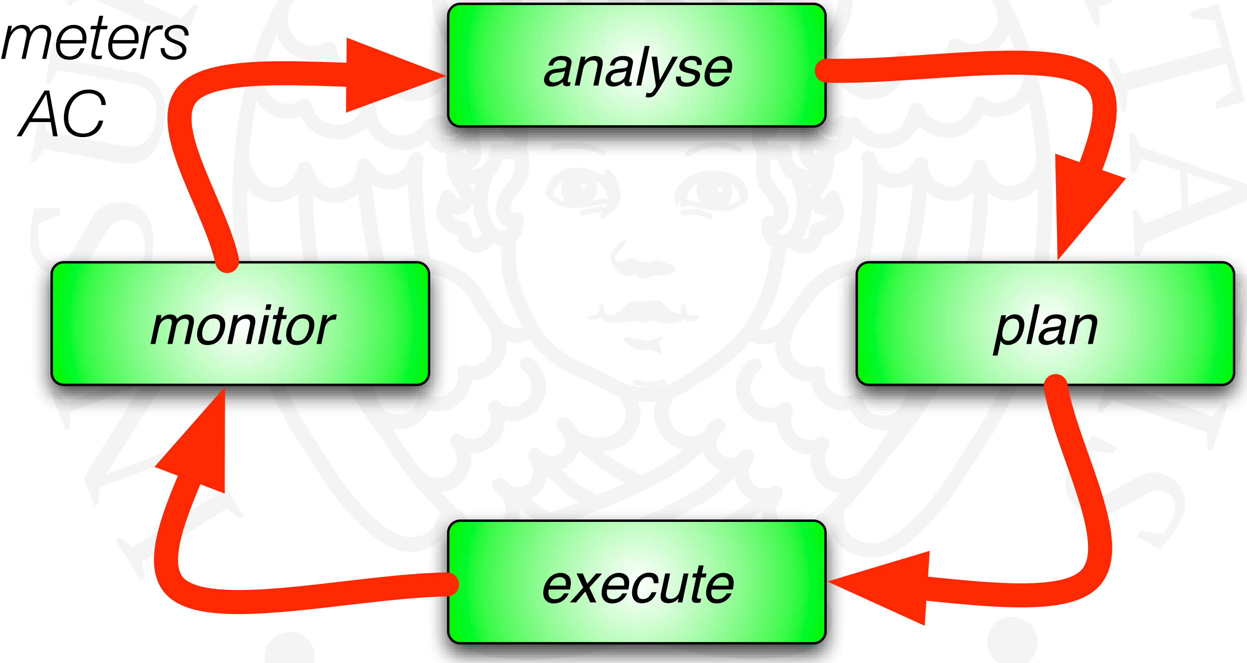
- policies and strategies
  - fired upon conditions on the current computation status
  - actuated through sequences of actions
- most naturally expressed by
  - (business) rule system

Business rule system

★ Set of pre-condition(params) → action(params) *rules*

- **if** pre-condition(params)==**true then** apply action(params)
- possibly
  - more than a single rule pre-condition holds at a time
  - priorities + algorithms (e.g. Rete) to solve conflicts/order rules

AM with rules



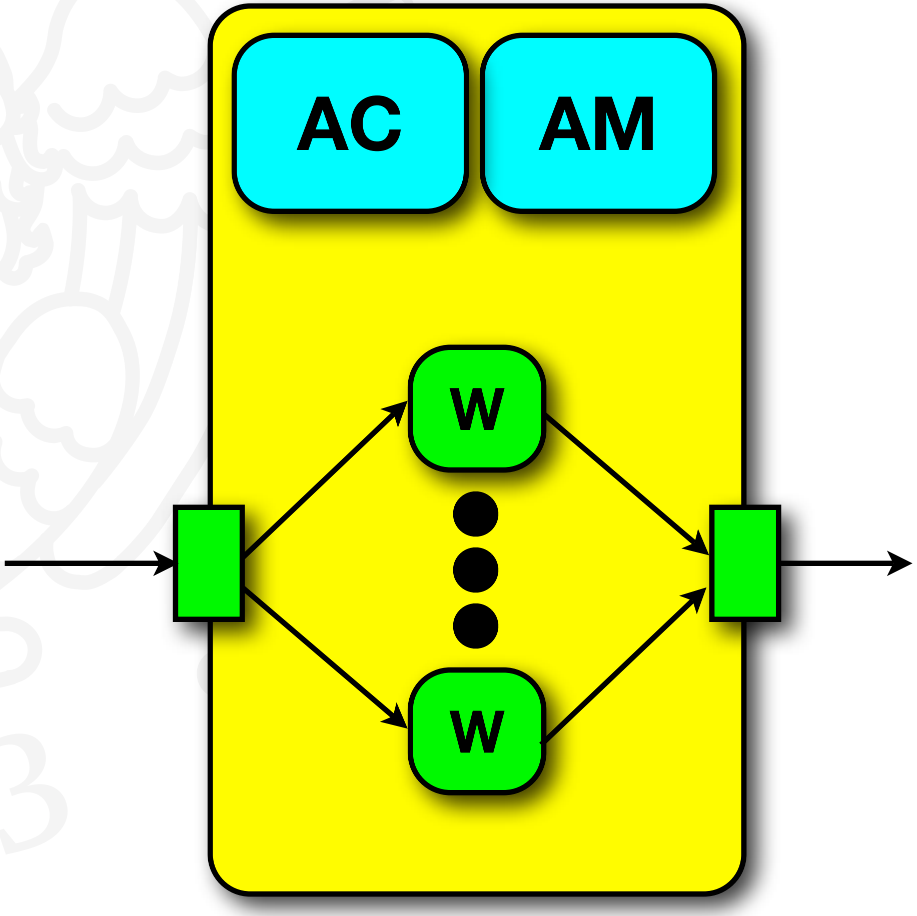
Lookup for fireable rules (solving conflicts)

Fetch parameters through AC

Actuate rule right hand section through AC

Sample behaviour (AM)

- ★ Initially:
  - rules used to customize the AM
- ★ Steady state
  - AM → autonomic cycle
- ★ Rule firing
  - AM performs actions through AC



Sample behaviour (AM)

pre(p_1,...,p_n) → act(p_1,...,p_n)

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★ Steady state

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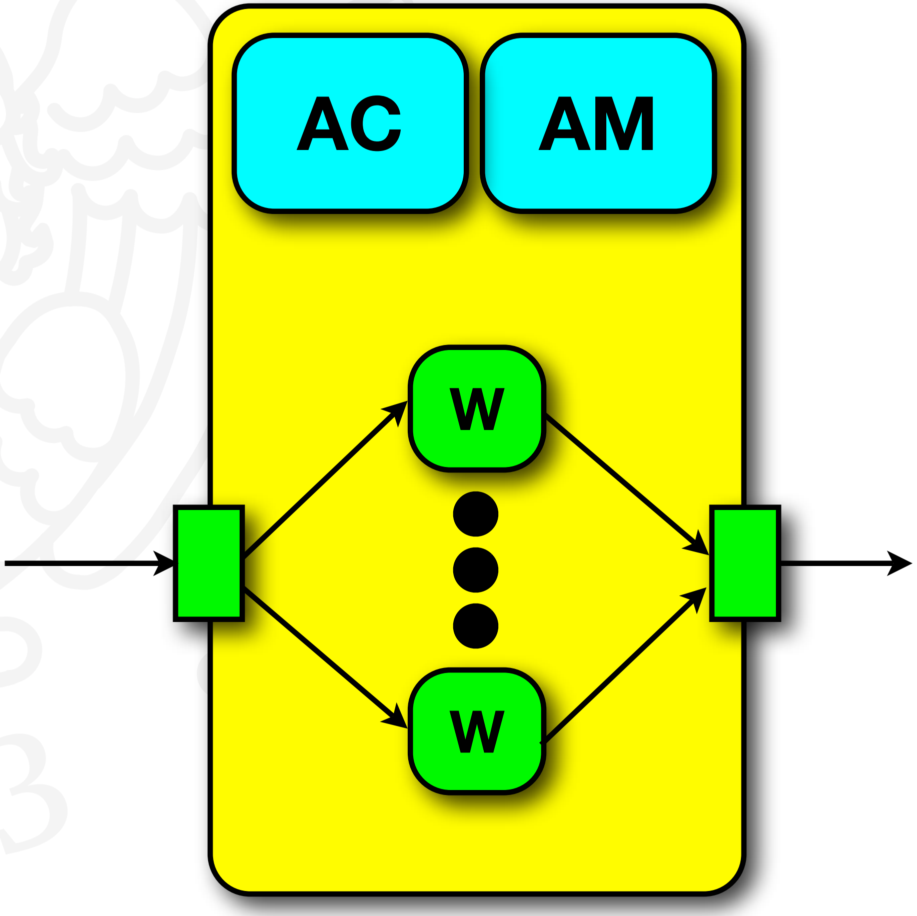

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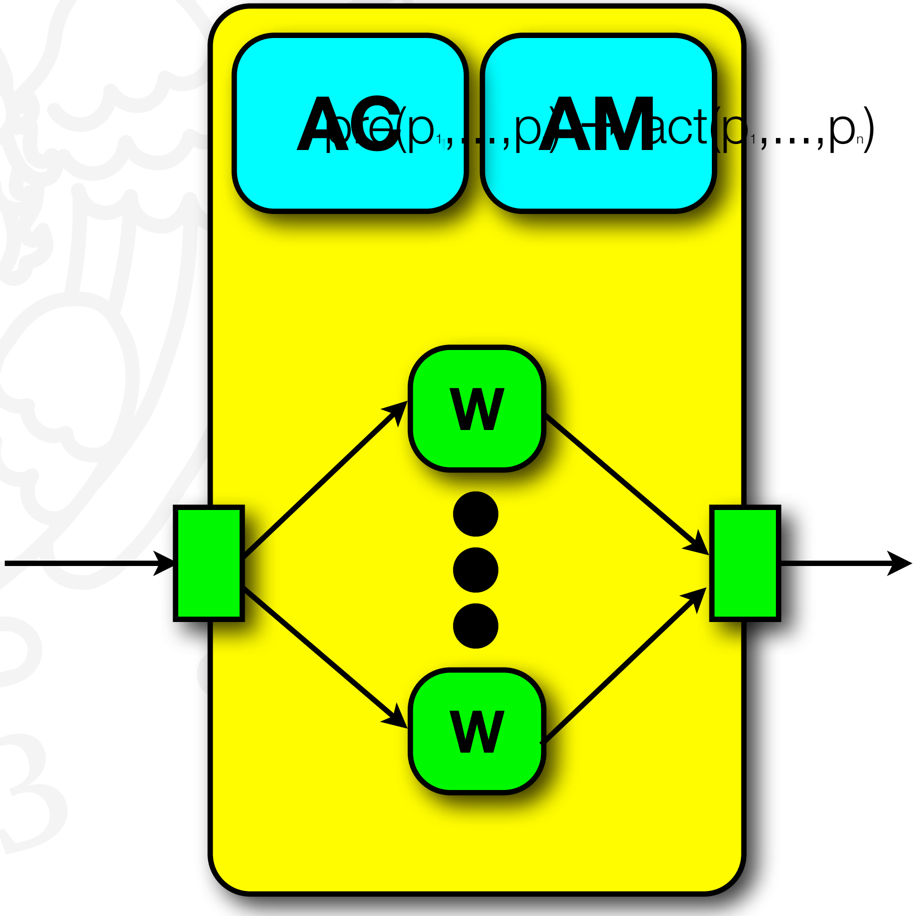

$pre(p_1,\ldots,p_n) \rightarrow act(p_1,\ldots,p_n)$

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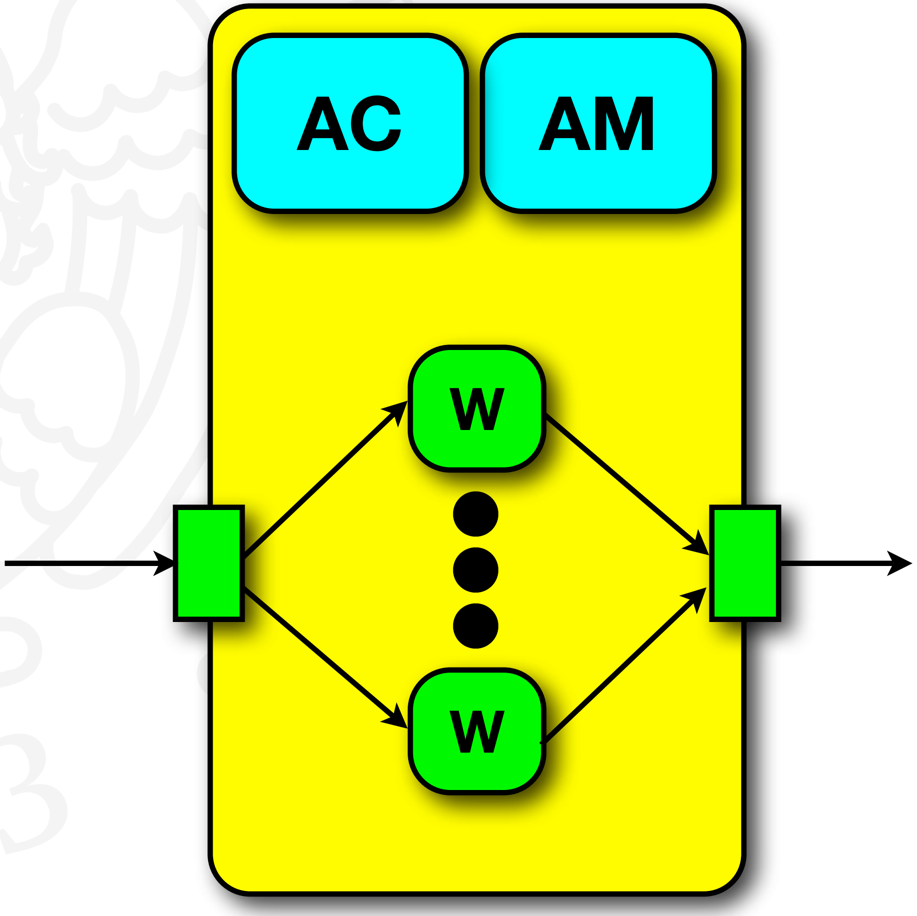

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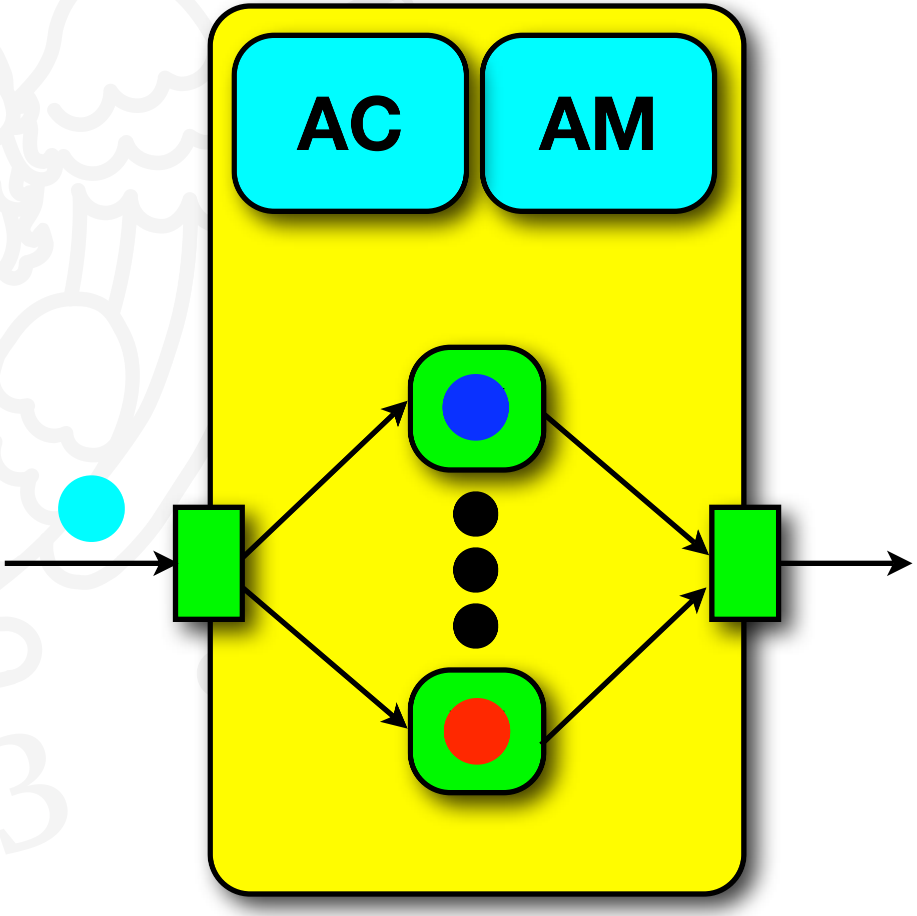

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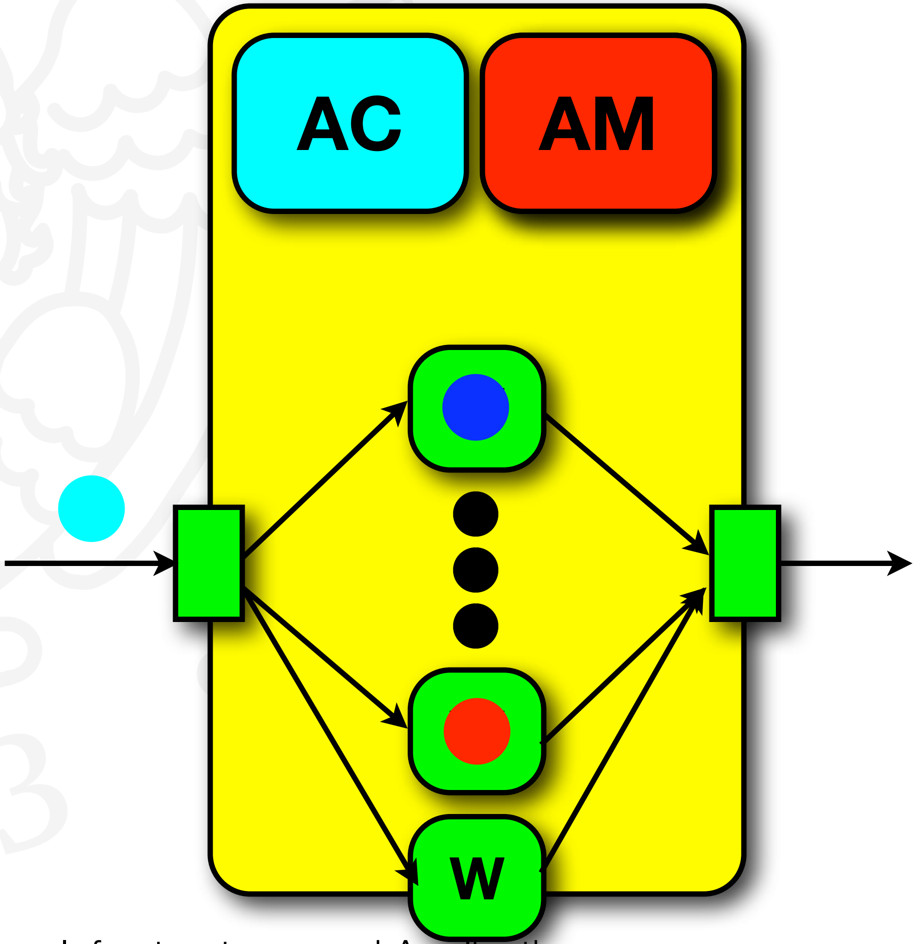

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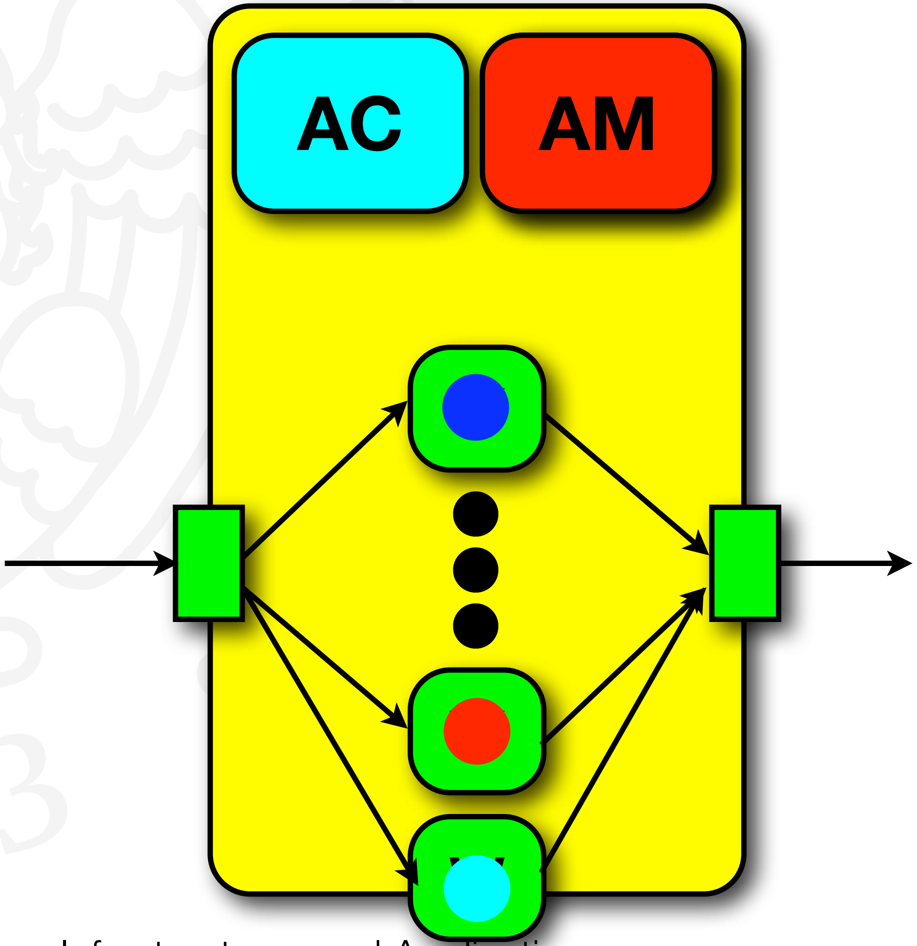

Sample rules (Jboss/GridCOMP GCM BS)

```
rule "CheckInterArrivalRate"
  salience 5
  when
     $arrivalBean : ArrivalRateBean( value <  ManagersConstants.LOW_PERF_LEVEL)
  then
     $arrivalBean.setData(ManagersConstants.notEnoughTasks_VIOL);
     $arrivalBean.fireOperation(ManagerOperation.RAISE_VIOLATION);
     System.out.println( "InterArrivalTime not enough - Raising a violation");
end
rule "CheckRateLow"
  when
     $departureBean : DepartureRateBean( value < ManagersConstants.LOW_PERF_LEVEL )
     $parDegree: NumWorkerBean(value <= ManagersConstants.MAX_NUM_WORKERS)
  then
      $departureBean.fireOperation(ManagerOperation.REPLICATE_SHARE);
     $departureBean.fireOperation(ManagerOperation.BALANCE_LOAD);
     System.out.println( "Adding "+ManagersConstants.ADD_WORKERS+ "workers");
end
rule "CheckRateHigh"
  when
     $departureBean : DepartureRateBean( value > ManagersConstants.HIGH_PERF_LEVEL )
     $parDegree: NumWorkerBean(value > ManagersConstants.MIN_NUM_WORKERS)
  then
     $departureBean.fireOperation(ManagerOperation.KILL);
     $departureBean.fireOperation(ManagerOperation.BALANCE_LOAD);
     System.out.println( "Rate "+$departureBean.getValue()+" (Removing 1 workers)");
end
```

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Which kind of applications ?

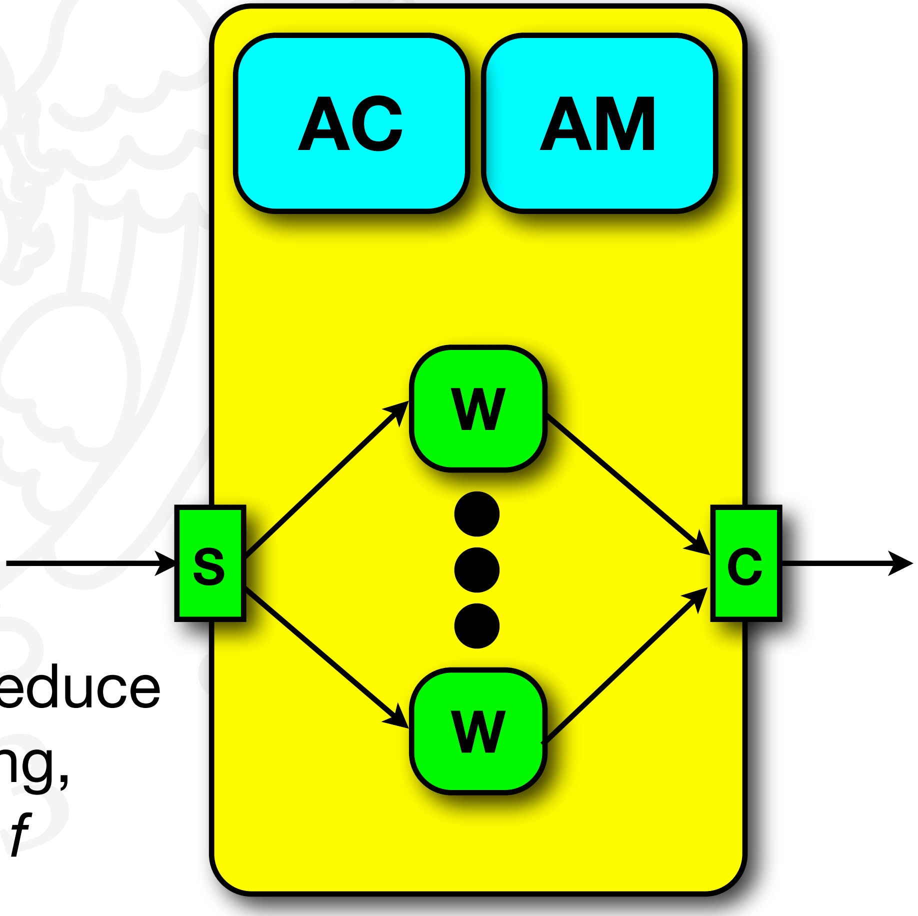
★ any one matching BS semantics

- e.g. task farm BS
  - image processing (e.g. noise reduction, medical image rendering)
  - parameter sweeping (e.g. financial data processing)
  - number crunching (e.g. FFT or LU co-processor)
- semantics: independent computations, same function, stream/ bunch of tasks

Behavioural skeletons

★ Functional replication BS

- meta BS with parameters
  - S: the task distribution policy
  - C: the result gathering policy
  - AM: the management policies



- *Farm*: S=unicast, C=gather
  Data Parallel: S=scatter, C=gather/reduce
  Fault tolerant: S=broadcast, C=voting, Wi=different algorithm for the same *f*

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Pisa research activity in the field

1990

P3L

skeleton only
no autonomic management
parallelism degree computed dynamically

muskel

(task farm) skeleton only
first autonomic manager
main goal: fault tolerance

2000

ASSIST

coordination language + skeleton(s)
primitive autonomic management
for task farm and pipeline computations

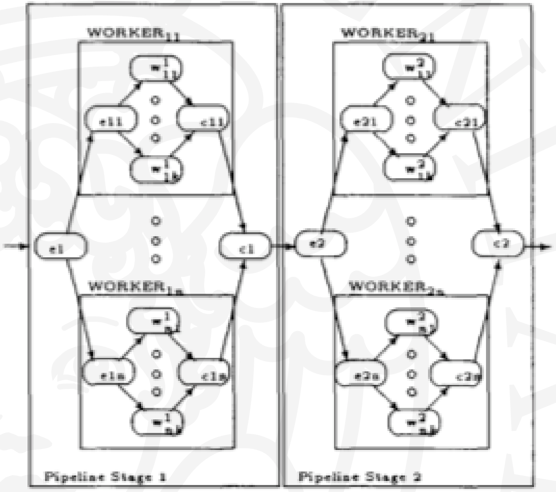
GCM

behavioural skeleton
fully fledged autonomic management
main goal: performance management/tuning

2010

P3L

- ★ Pisa Parallel Programming Language
  - joint project Dept. Computer Science & HP Pisa Science
  - first working skeleton based framework



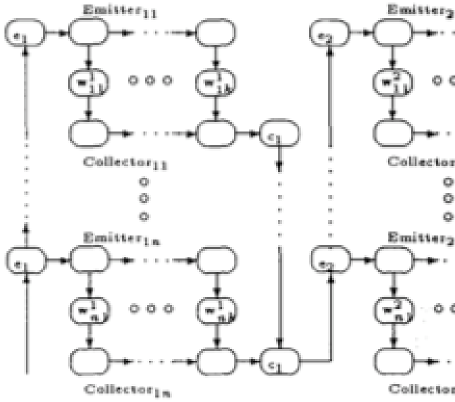


Figure 2: Mapping of the example proc
2D mesh architecture

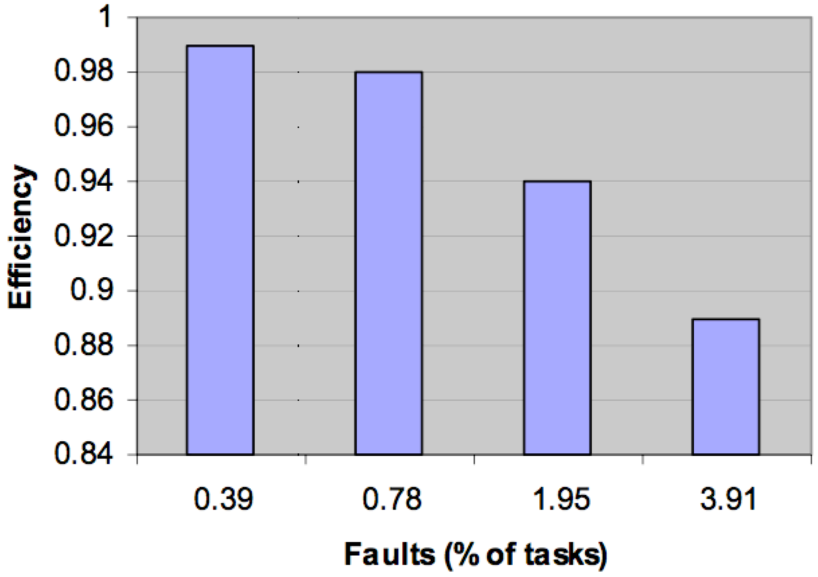
P3L (Prolog compiler targetting Meiko CS/2, ‘91) ➝ Anacleto (open source, C + MPI host code, compiler, ‘95) ➝ SkIE (C, C++, F77, Java + MPI host code compiler ‘96) ➝ ...

- scalability demonstrated, range of applications within PQE2000 (Italian national project, with QSW and other University, CNR bodies)

Muskel

★ micro SKEleton Library

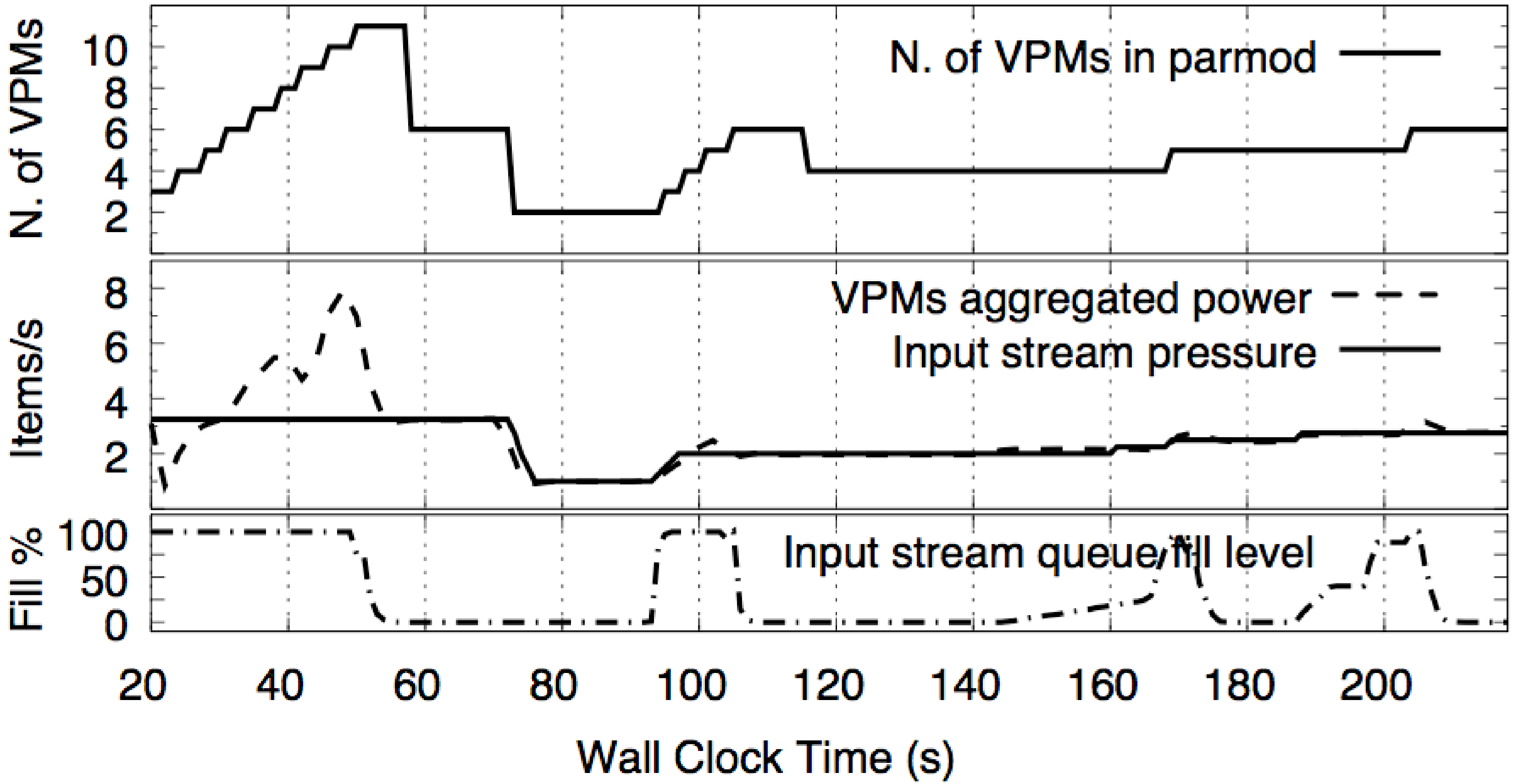
- full Java/RMI skeleton library
- task farm + pipeline skeletons
- translated to macro data flow code
- executed by a distributed interpreter
- with manager ensuring parallelism degree contract



Synthetic application

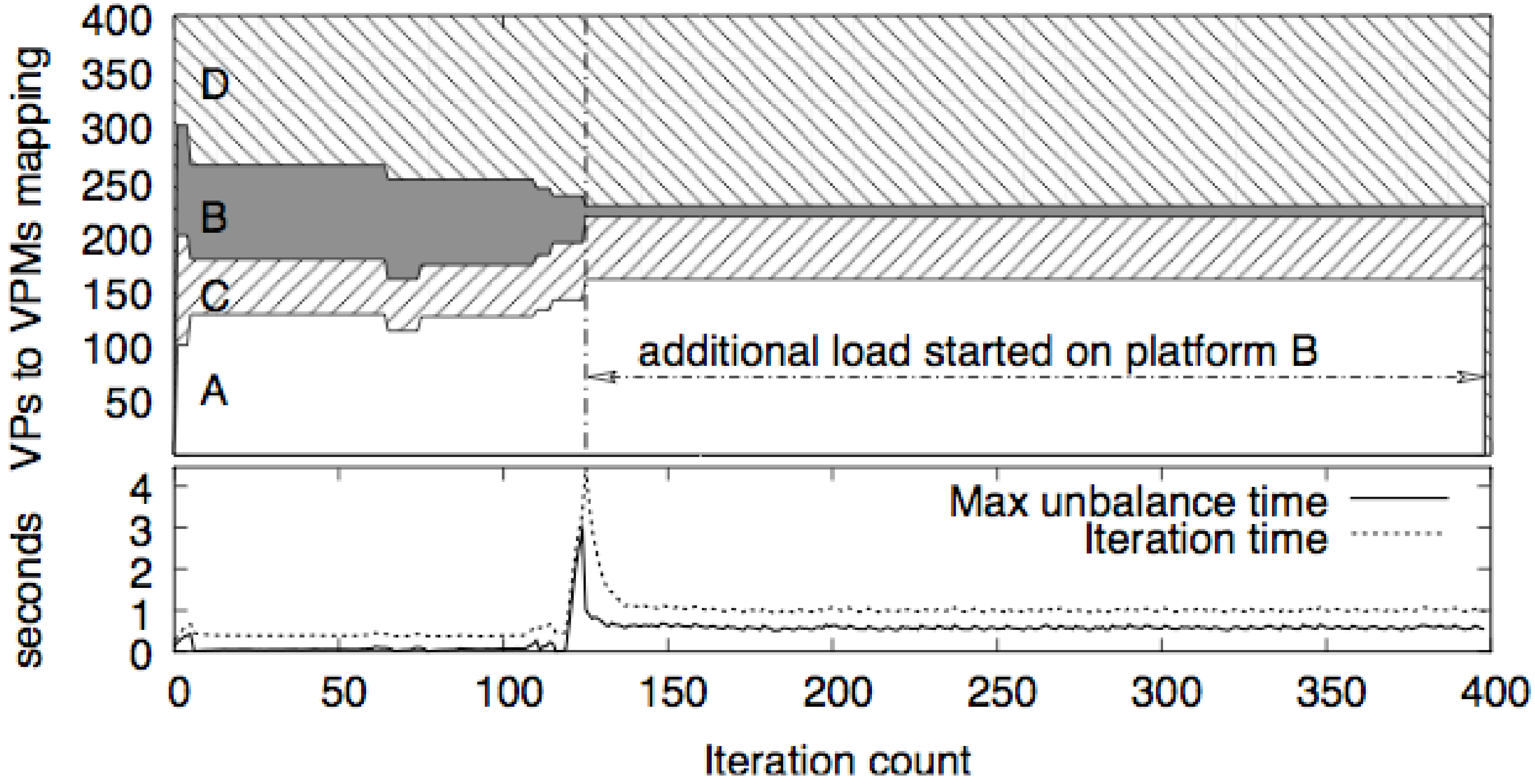
ASSIST: task farm

Synthetic application



ASSIST: data parallel

Synthetic application



ASSIST + muskel

Jacobi/Madelbrot/ MM applications

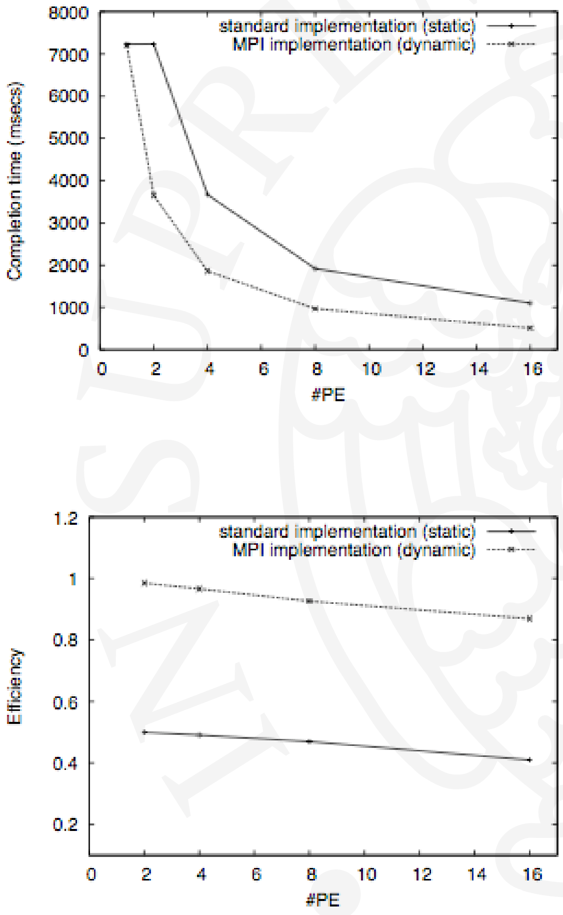


Figure 4. Dynamic (MPI `parmod`) vs. static (ASSIST) implementation of `parmod`: unbalanced computation case: completion times (upper) and efficiency (lower)

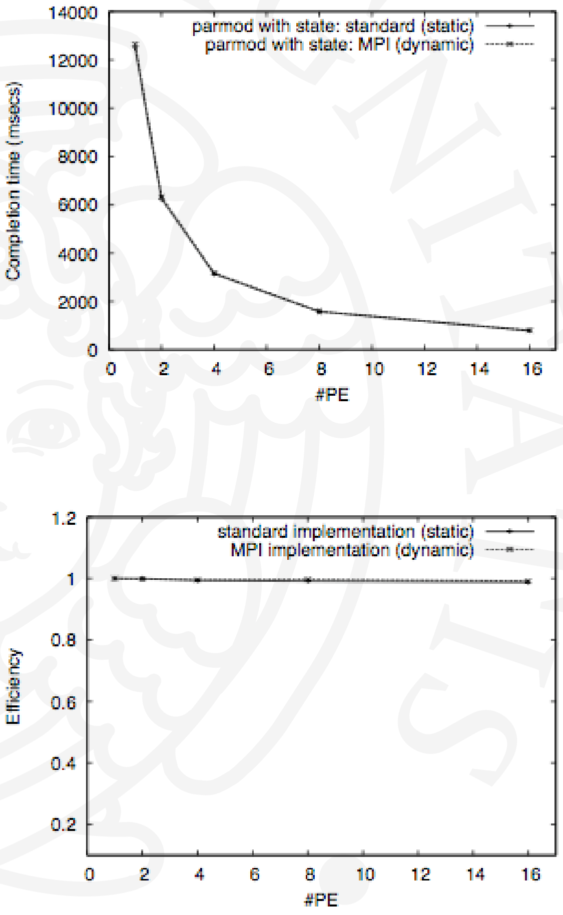


Figure 5. Dynamic (MPI `parmod`) vs. static (ASSIST) implementation of `parmod`: balanced computation case: completion time (upper) and efficiency (lower)

GCM

★ Grid Component Model

- developed within CoreGRID +
  reference implementation within GridCOMP

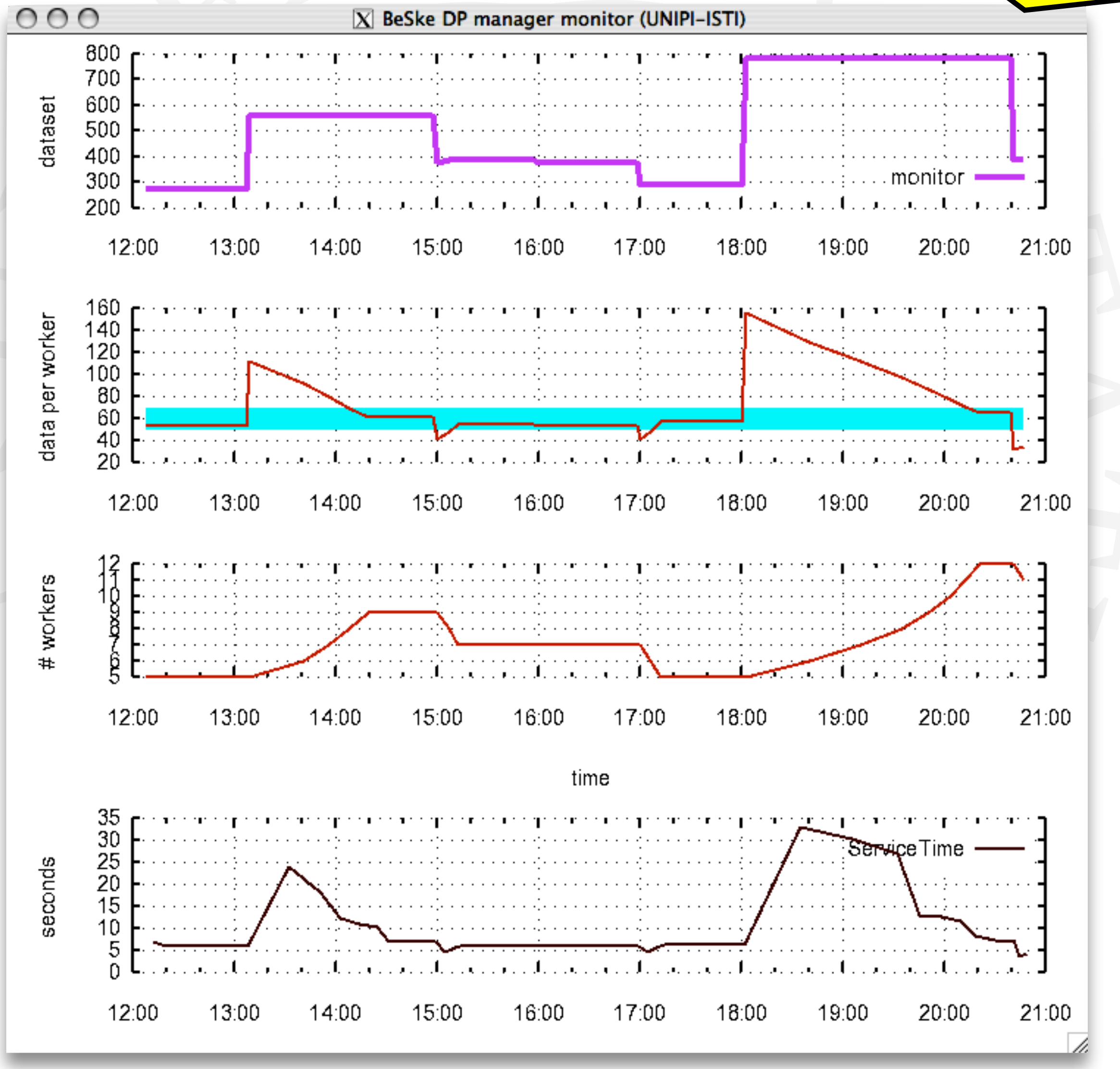
- behavioural skeleton concept introduced

  - reuses most of the ASSIST experience

- AM based on JBoss rule engine

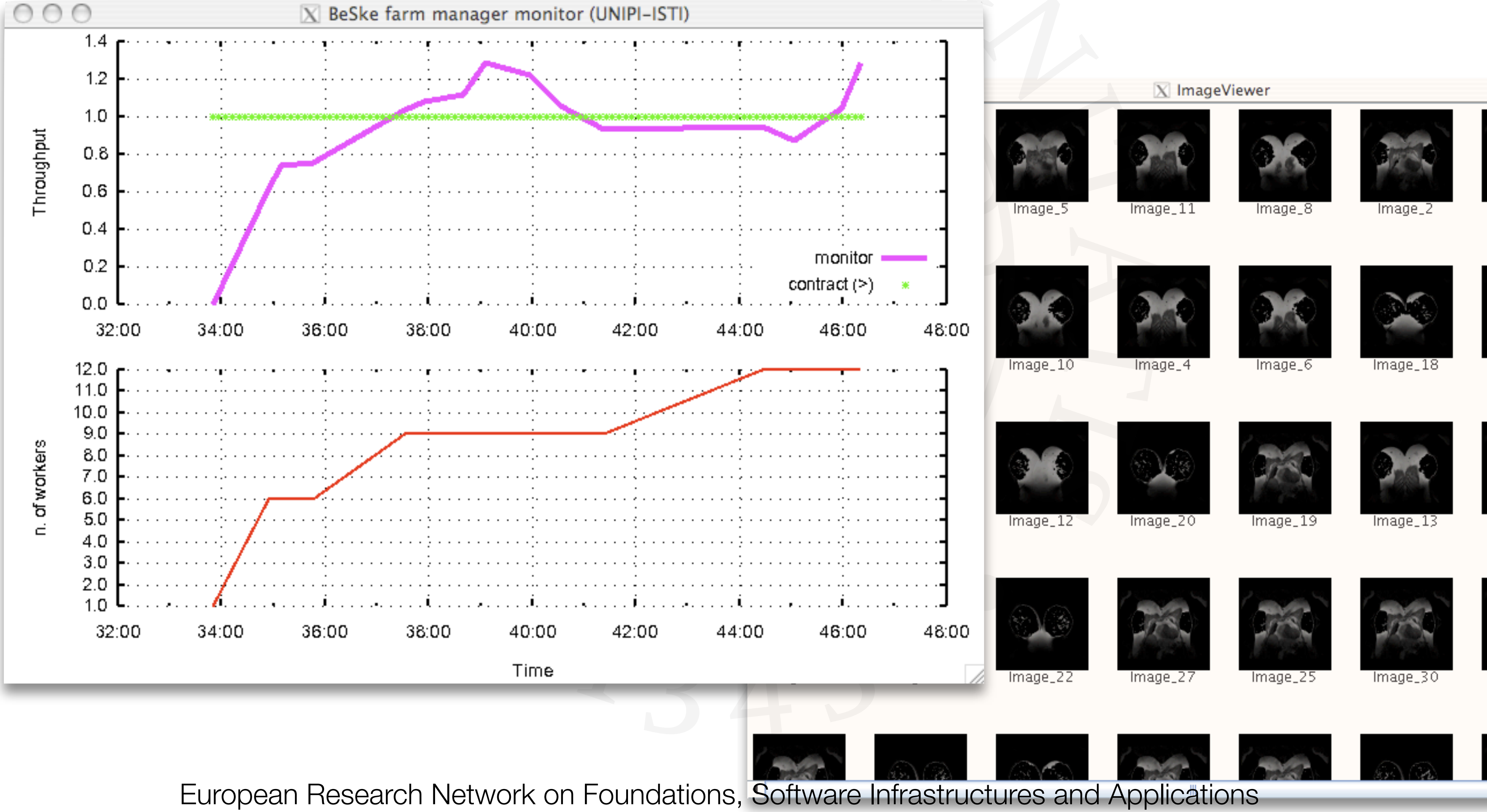
GCM: data parallel adaptation

Biometric identification



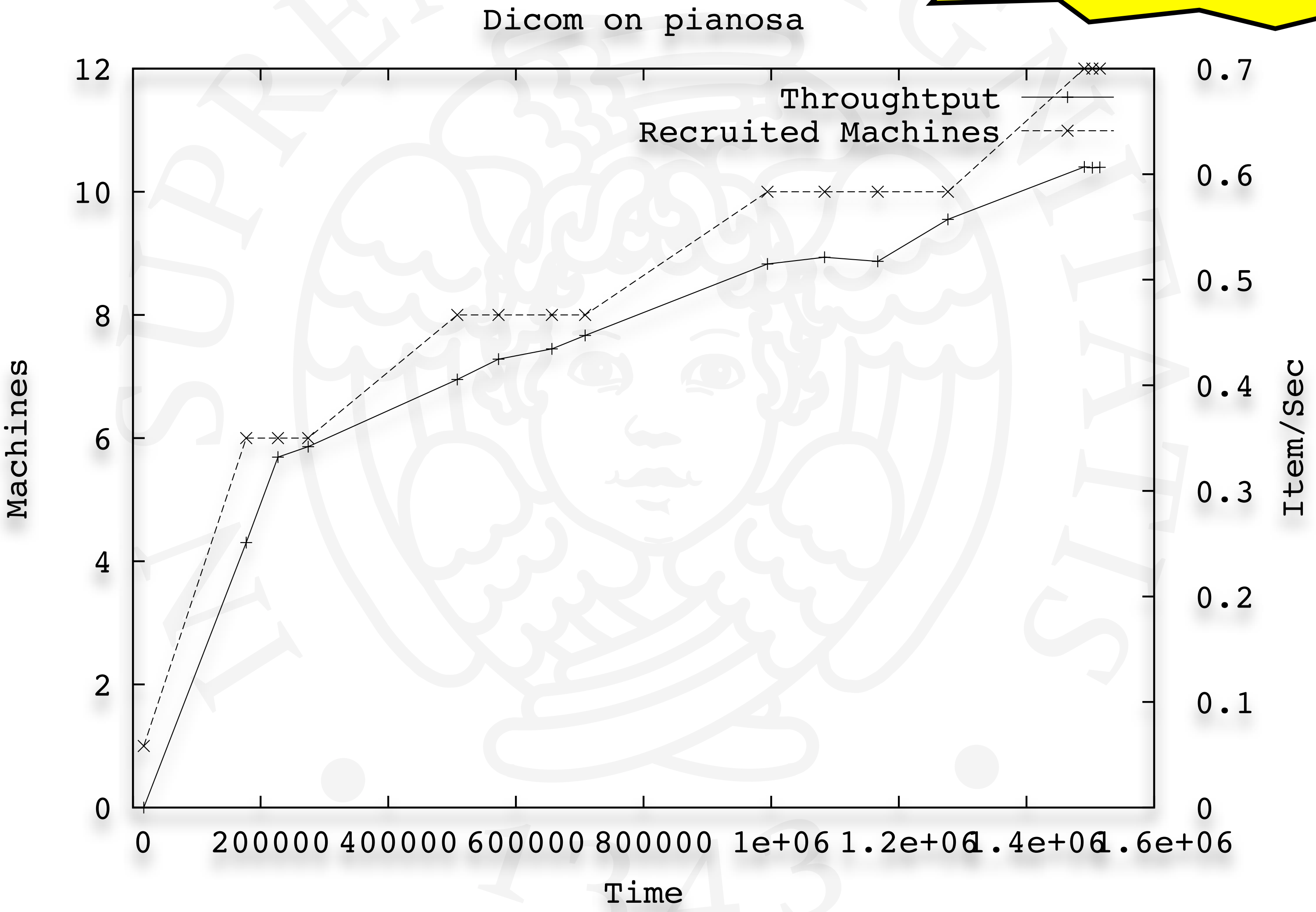
GCM: task farm performance mana

Medical image processing



GCM: task farm

Medical image processing



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Ongoing work

- ★ Fully fledged, hierarchical, rule based autonomic managers for behavioural skeletons
  - contract propagation in the BS tree
    - user defined top level contracts (SLAs)
    - derived inner contracts
  - experimenting composition strategies & policies
- ★ Proactive rules
  - e.g. re-considering temporarily unavailable resources
    - computation completely unrelated events trigger rules
    - rules set up new execution frameworks

Ongoing work (2)

★ exploitation of historical data

- applies to proactive and reactive adaptation

★ (semi-)formal tools supporting manager design and development

★ merging with software engineering and agent pre-existing and complementary results

Conclusions

★ Large experience

- currently finalized to GCM, Muskel and ASSIST frameworks

★ So many things to do !

★ But definitely:

- important and effective tools to support efficient massively parallel/distributed programming

Acknowledges to: *M. Aldinucci, S. Campa, G. Zoppi (Univ. Pisa), P. Kilpatrick (Queen's Univ, Belfast), P. Dazzi (ISTI/CNR Pisa)*

Thank you for your attention

¿ Any questions ?