RESOURCE MANAGEMENT

Chapter 11: Parallel and Distributed Software Systems

OUTLINE

11.1 Definition

11.2 Resource allocation algorithms

11.3 Autonomic resource allocation

11.4 Control theory

11.5 Performance models

11.6 Virtualized environments

DEFINITION

- Allocation of resources:
  - Crucial in distributed systems
  - To make sure applications run properly
  - Feedback to applications required

- Different type of resources:
  - CPU, memory, bandwidth and storage

- Objectives:
  - Minimize response times of applications

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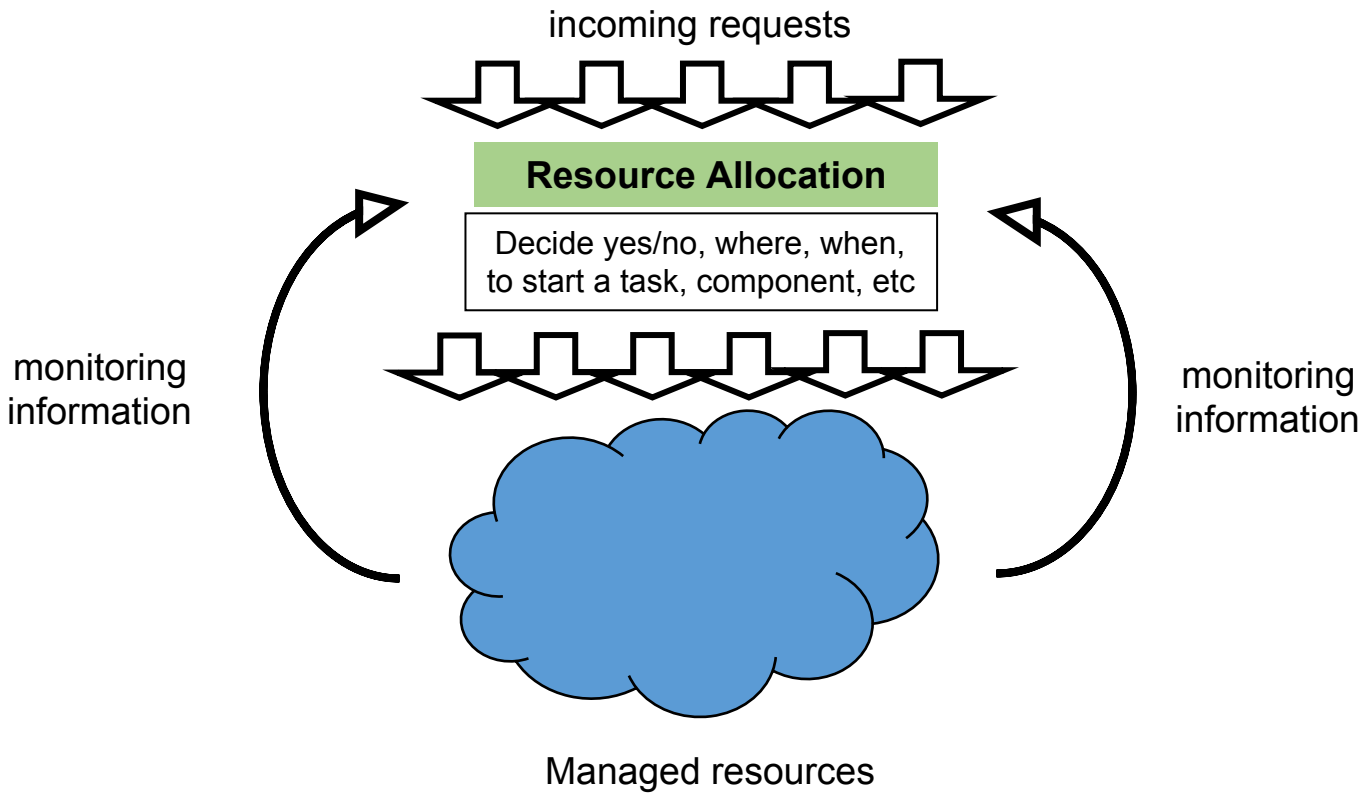
RESOURCE ALLOCATION

1. Definition



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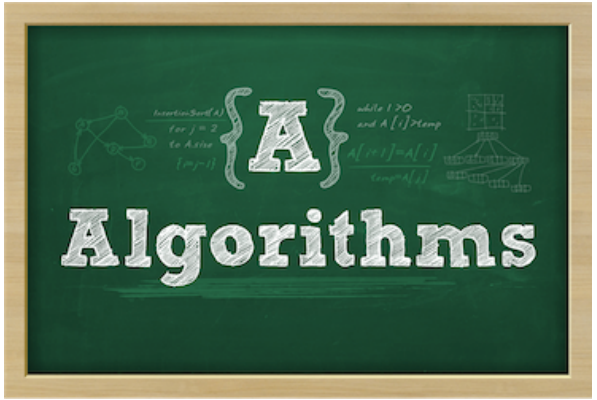
RESOURCE ALLOCATION ALGORITHMS



Different types:

- Single request versus batch
- Optimal versus heuristical
- Online versus off-line
- Static versus dynamic

Models required:

- Resource models
- Request models

next:

- Integer Linear programming
- Metaheuristics
- Greedy algorithms

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INTEGER LINEAR PROGRAMMING

$$\begin{aligned} \text{maximize} \quad & \mathbf{c}^{\mathrm{T}}\mathbf{x} \\ \text{subject to} \quad & A\mathbf{x} \leq \mathbf{b}, \\ & \mathbf{x} \geq \mathbf{0}, \\ \text{and} \quad & \mathbf{x} \in \mathbb{Z}, \end{aligned}$$

Optimal solution

Scalability ?!

Example:

$$\begin{cases} x_1+x_2+x_3+x_4+x_5 \leq 8 \\ 6x_1-x_3+x_5 \leq 25 \\ x_1-x_2-2x_3 \leq 4 \\ 3x_4-x_5 \leq 3 \\ \\ x_1,x_2,x_3,x_4,x_5 \geq 0 \\ x_1,x_2,x_3,x_4,x_5 \leq 100 \end{cases}$$

constraints

$$\max(x_1+x_2+2x_3-x_4-3x_5)$$

objective function

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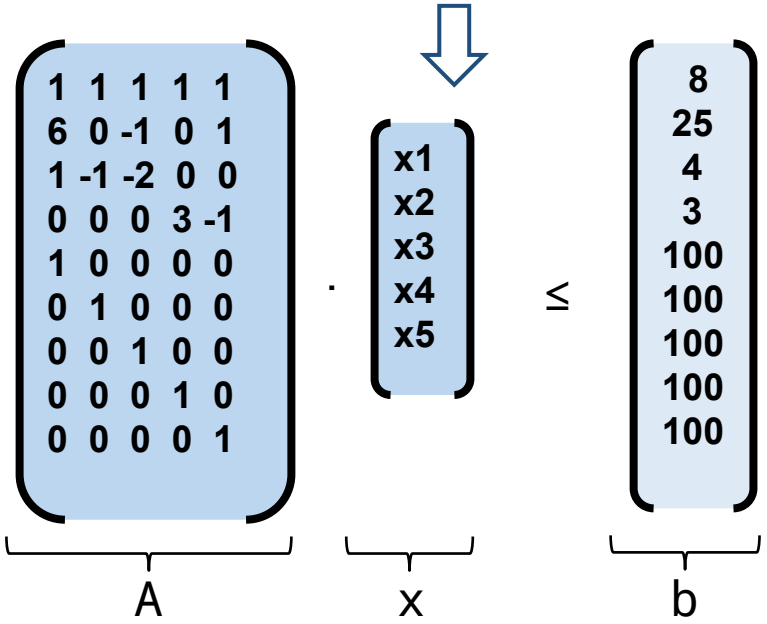
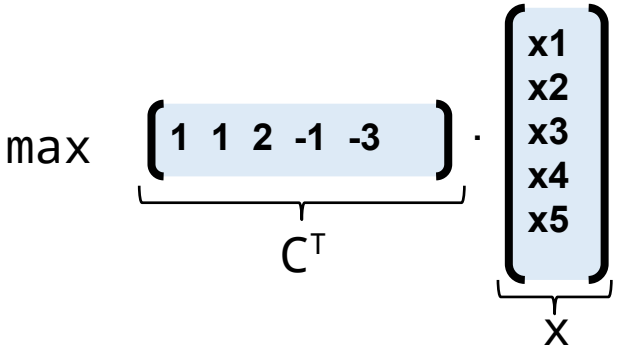
INTEGER LINEAR PROGRAMMING





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INTEGER LINEAR PROGRAMMING

ILP methodology:

1. determine the decision variables and constraints
2. this provides the description of the vector x,
   and the values for the matrix A, vector b and c
3. a solver package then determines based on A, b and c:
   a. the values of the optimal x vector
   b. the feasibility of the solution

e.g. iLog CPLEX solver

- Simplex algorithm
- Branch and Bound algorithm

INTEGER LINEAR PROGRAMMING

Important :

1. solution process can be stopped after certain amount of time
2. deviation (in %) from optimal solution is available!

Decision variables in x:

can be:

1. resource utilization
2. resource allocation (which job on which machine)
3. binary decision which machine is switched on
4. binary decision whether a software component is assigned to a machine or not

INTEGER LINEAR PROGRAMMING

Example 1:

$$
\begin{array}{lllll}
\min & \displaystyle\sum_{i\in L}\sum_{j\in F} c_{ij}x_{ij} + \sum_{j\in F} f_j y_j & & & \\
\text{s.t.} & \displaystyle\sum_{j\in F} x_{ij} & = 1 & \forall i \in L & \text{(assign\_def)} \\
 & x_{ij} & \leq y_j & \forall i \in L, j \in F & \text{(link)} \\
 & \displaystyle\sum_{i\in L} d_i x_{ij} & \leq C y_j & \forall j \in F & \text{(capacity)} \\
 & x_{ij} \in \{0,1\} & & \forall i \in L, j \in F & \\
 & y_j \in \{0,1\} & & \forall j \in F &
\end{array}
$$

Example 2:

$$
\begin{array}{ll}
\min \displaystyle\sum_{i=0}^{n}\sum_{j\neq i, j=0}^{n} c_{ij}x_{ij} & \\
0 \leq x_{ij} \leq 1 & i,j = 0,\cdots,n \\
u_i \in \mathbf{Z} & i = 0,\cdots,n \\
\displaystyle\sum_{i=0, i\neq j}^{n} x_{ij} = 1 & j = 0,\cdots,n \\
\displaystyle\sum_{j=0, j\neq i}^{n} x_{ij} = 1 & i = 0,\cdots,n \\
u_i - u_j + n x_{ij} \leq n-1 & 1 \leq i \neq j \leq n
\end{array}
$$

Additional example in appendix!

INPUT PARAMETERS

TABLE I: The model input variables.

Symbol	Description
G	The graph $G = (N, E)$ representing the network.
N	The nodes within the network. This collection can be partitioned into a set of computational nodes N^c and a set of service nodes N^s.
E	The edges within the network.
E_n^{in}	The edges that are incoming in node $n \in N$.
E_n^{out}	The edges that are outgoing from node $n \in N$.
$C(e)$	The bandwidth capacity of an edge $e \in E$.
$L(e)$	The network latency of an edge $e \in E$.
$\mathcal{C}$	The service chains that must be allocated on the network.
$R^{VM}(C)$	The VM requests that are part of service chain $C \in \mathcal{C}$.
$R^s(C)$	The service requests that are part of service chain $C \in \mathcal{C}$.
$R(C)$	The resource requests that are part of service chain $C \in \mathcal{C}$. $R(C) = R^{VM}(C) \cup R^s(C)$.
S	The collection of all services that exist within the model.
$D^\gamma(r)$	The resources of type γ needed for a request r. This request can either be a service request or a VM request.
Γ^c	The resource types that are available on a physical computational node. Typically these resources are CPU and Memory.
Γ^s	The resource types that are provided by a service $s \in S$. Typically this is a service-specific resource such as requests per second.
$\mathcal{R}$	A collection containing all of the resource requests of all service chains in $\mathcal{C}$.
C_n^γ	The resource capacity of a node or service n. For computational nodes, $\gamma \in \Gamma^{VM}$. For service nodes offering service s, $\gamma \in \Gamma^s$. A service VM of a service s provides C_s^γ resources of types $\gamma \in \Gamma^s$.
$D(r_1, r_2)$	The network demand between requested VMs or services r_1 and r_2.
$L(r_1, r_2)$	The maximum network latency between requested VMs or services r_1 and r_2.

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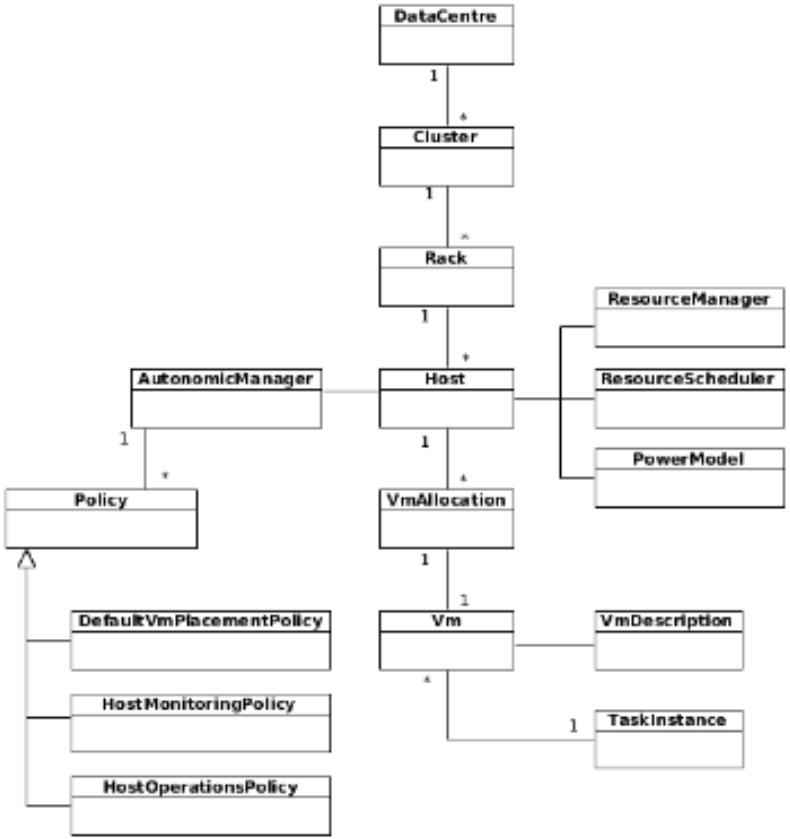
RESOURCE MODEL



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ILP SOLVERS

- e.g. iLog CPLEX solver

- Simplex algorithm
- Branch and Bound algorithm

- Execution times can be large
- Usage of HPC - after debugging!
- Stop criteria!

METAHEURISTICS

- Tabu search
- Simulated annealing
- Genetic programming (evolutionary algorithms)
- Ant-based algorithms or particle swarm algorithms (nature-inspired algorithms)

– Can serve as benchmarks (lower bound) for the exact solutions and the greedy algorithms.

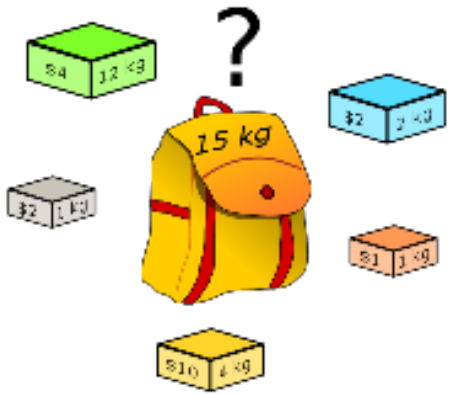
BIN PACKING ALGORITHMS

- objects of different volumes must be packed into a finite number of bins or containers, with a predetermined capacity C.
- goal: minimize the number of bins used.
- combinatorial NP-hard problem.
- greedy algorithm: **first fit algorithm**
  - fast but often non-optimal
  - placing each item into the first bin in which it will fit
  - can be made much more effective by first sorting the list of elements into decreasing order (also called first-fit decreasing algorithm)

KNAPSACK ALGORITHMS

Special case of bin packing algorithm:

- number of bins is restricted to 1
- each item is characterised by both a volume and a value
- the problem of maximizing the value of items that can fit in the bin



AUTONOMIC RESOURCE ALLOCATION

Structure:

3.1 Autonomic Systems

- Goal
- Adaptive vs. Autonomic
- Use cases

3.2 Control Loops

- MAPE
- OODA
- FOCALE

3.3 Architecture for distributed autonomic systems

3.4 Knowledge representation

3.5 Reasoning

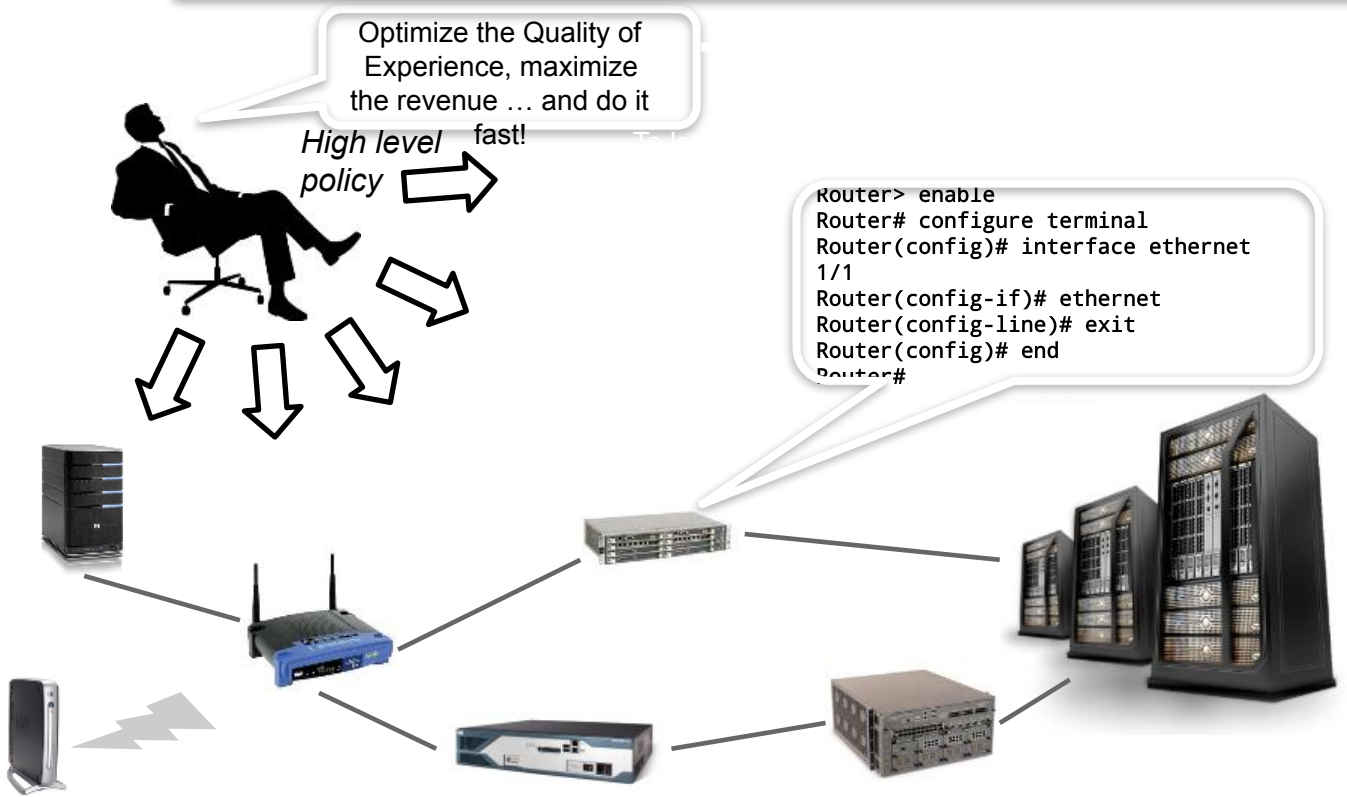
AUTONOMIC SYSTEMS

The system adapts its behavior to changes in
The environment
End-user needs
Service requirements

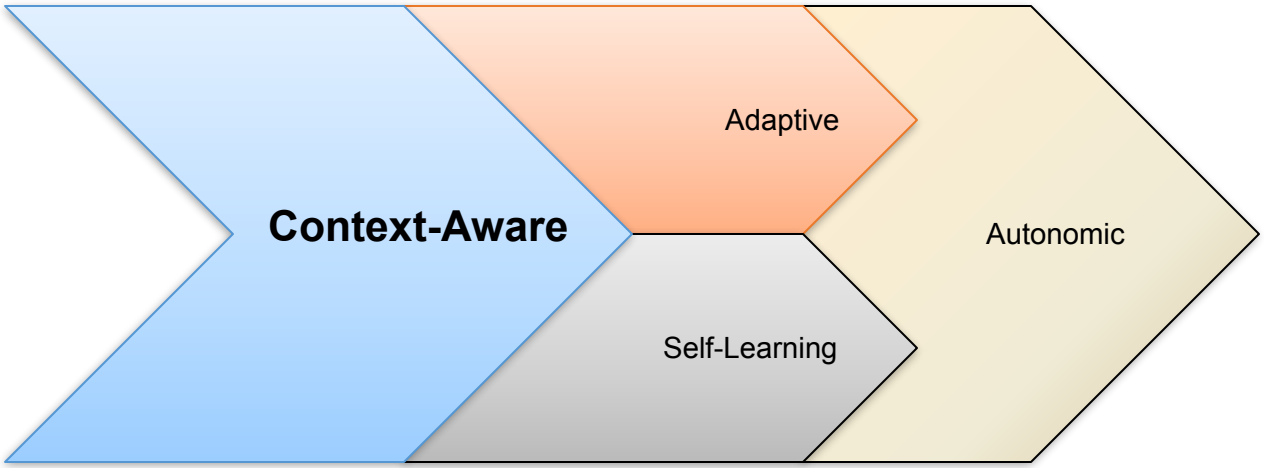
It is governed by high-level policies
Representing business goals
Defined and managed by human operators

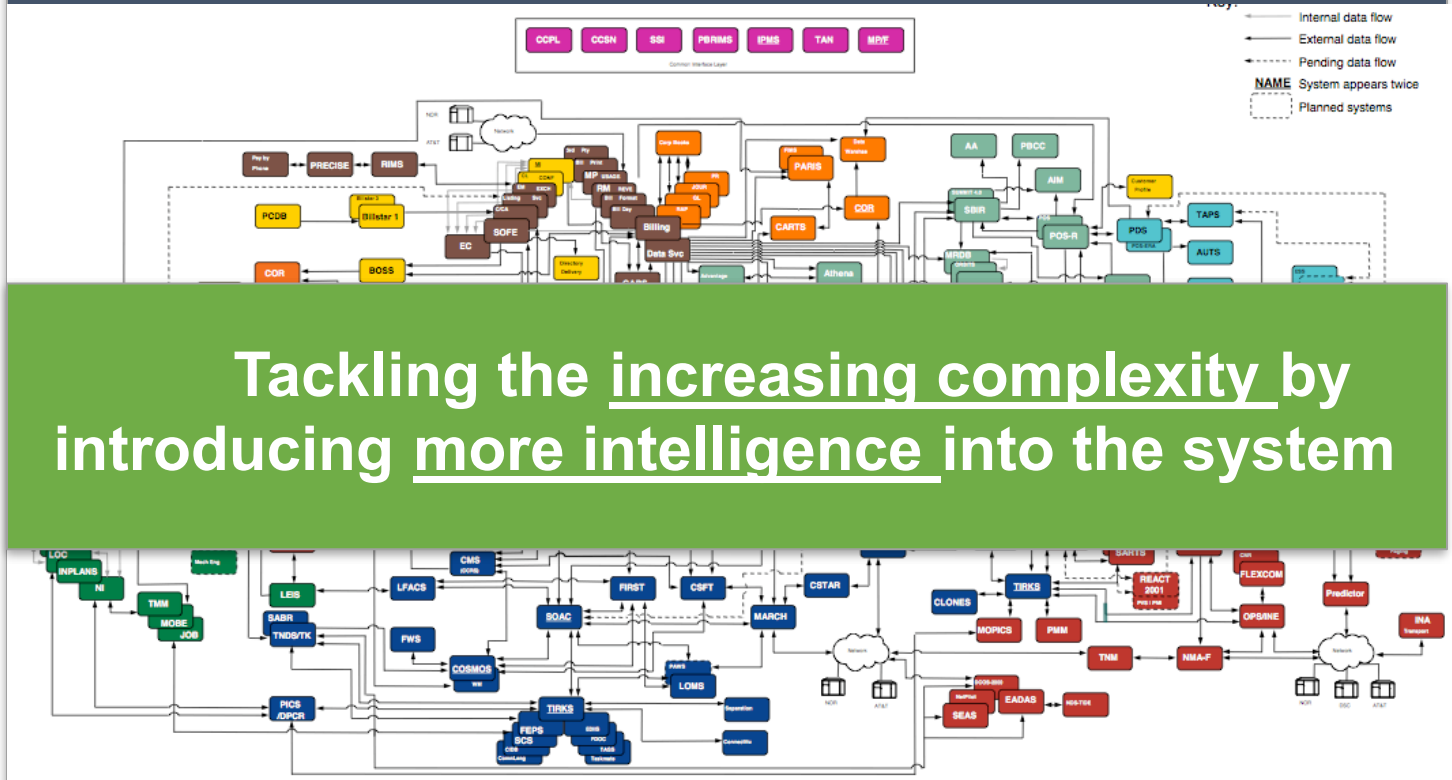
THE GOAL OF AUTONOMIC SYSTEMS

Autonomic systems decrease management complexity by performing low-level configurations themselves



ADAPTIVE VS. AUTONOMIC





Tackling the increasing complexity by introducing more intelligence into the system

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USE CASES

Cloud Computing

eHealth

Intelligent Transportation

Robotics

How do we design and implement an autonomic system?

DEFINITION – 4 CHARACTERISTICS

- Self chop characteristics:

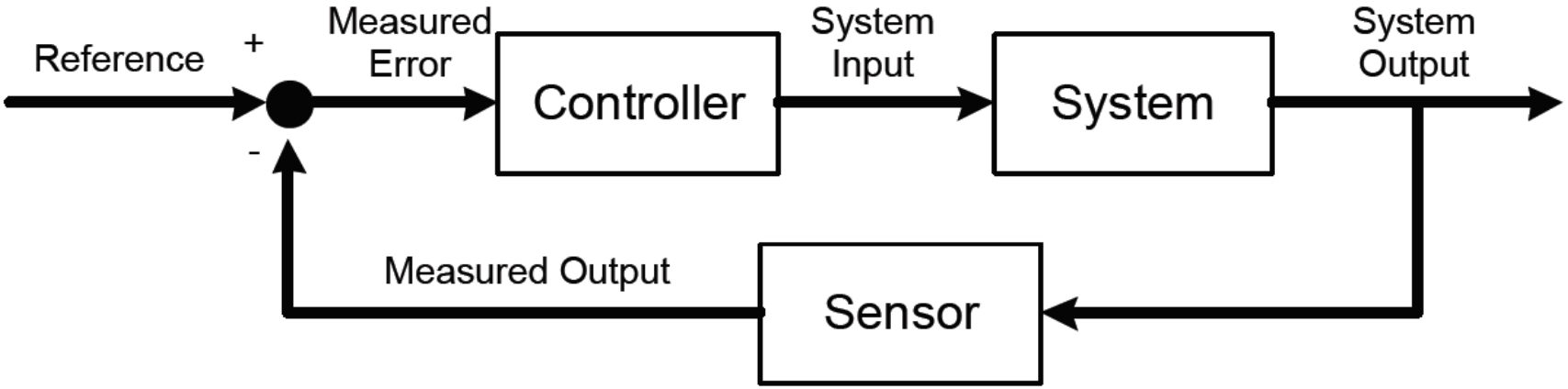
Self-configuration

Self-healing

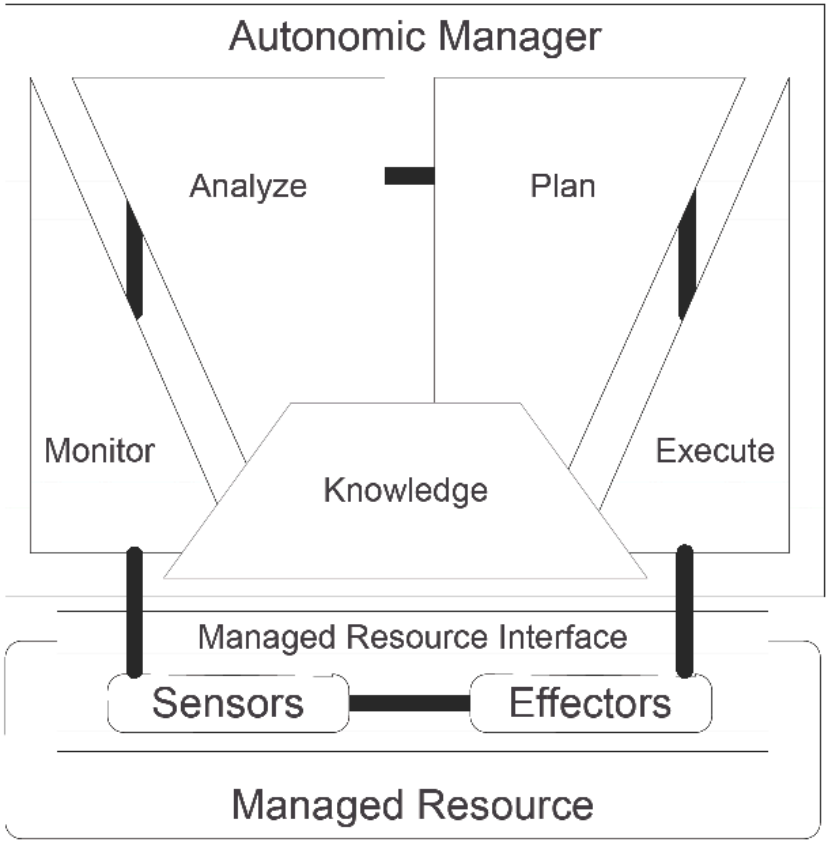
Self-optimization

Self-protection

CONTROL LOOPS



MAPE CONTROL LOOP



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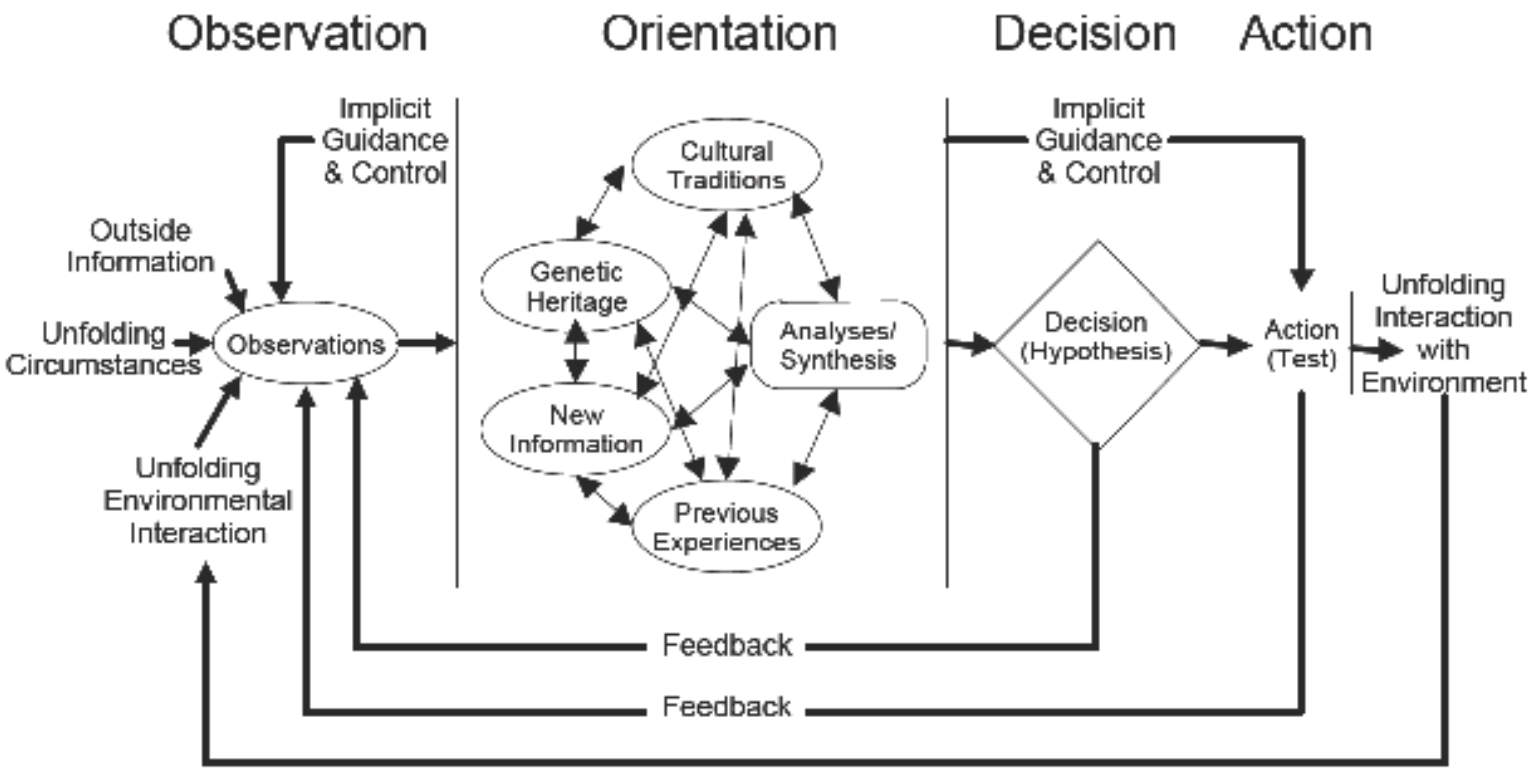
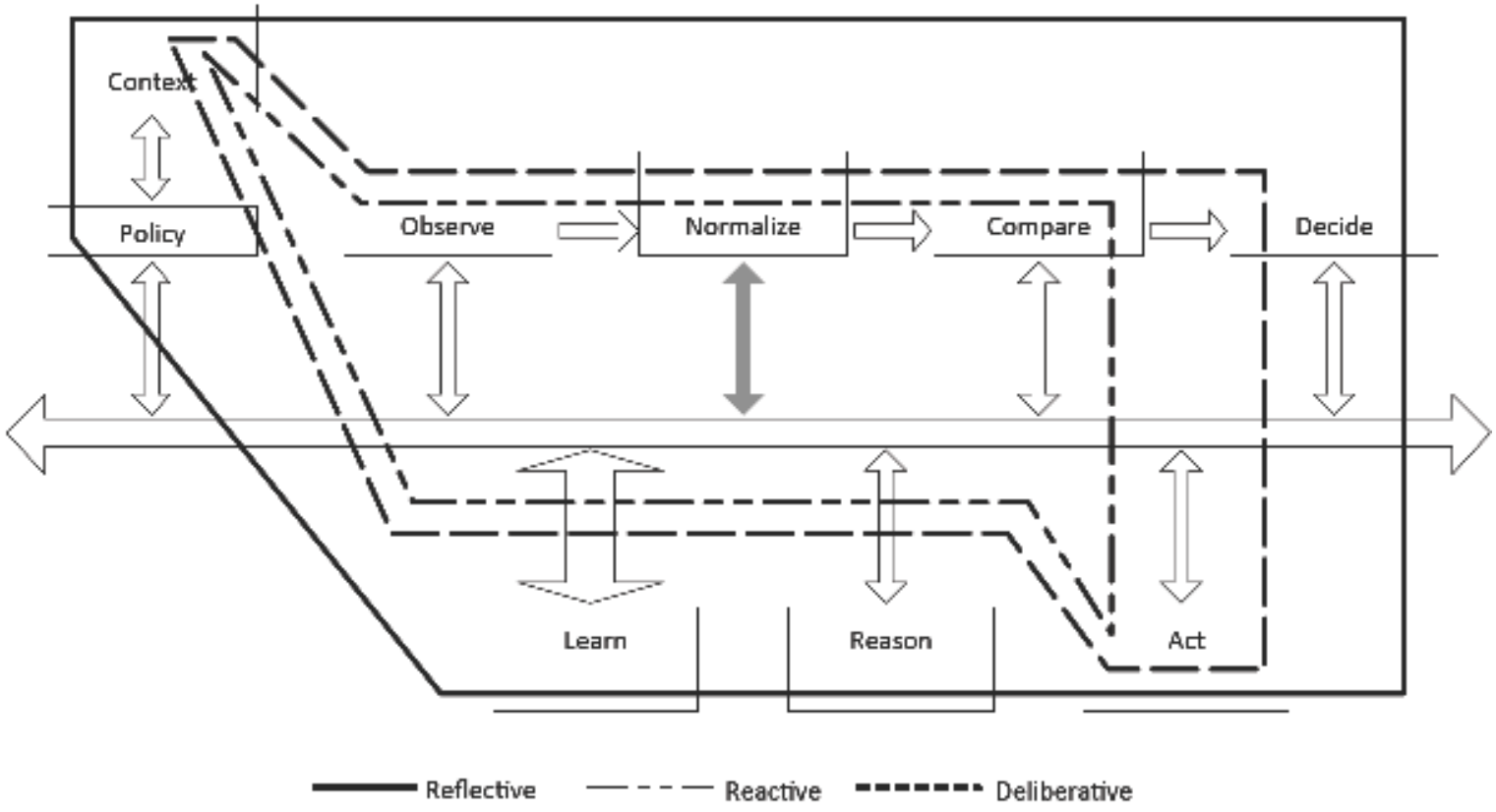
OODA CONTROL LOOP



FOCALE CONTROL LOOP



CONTROL LOOP EXAMPLE