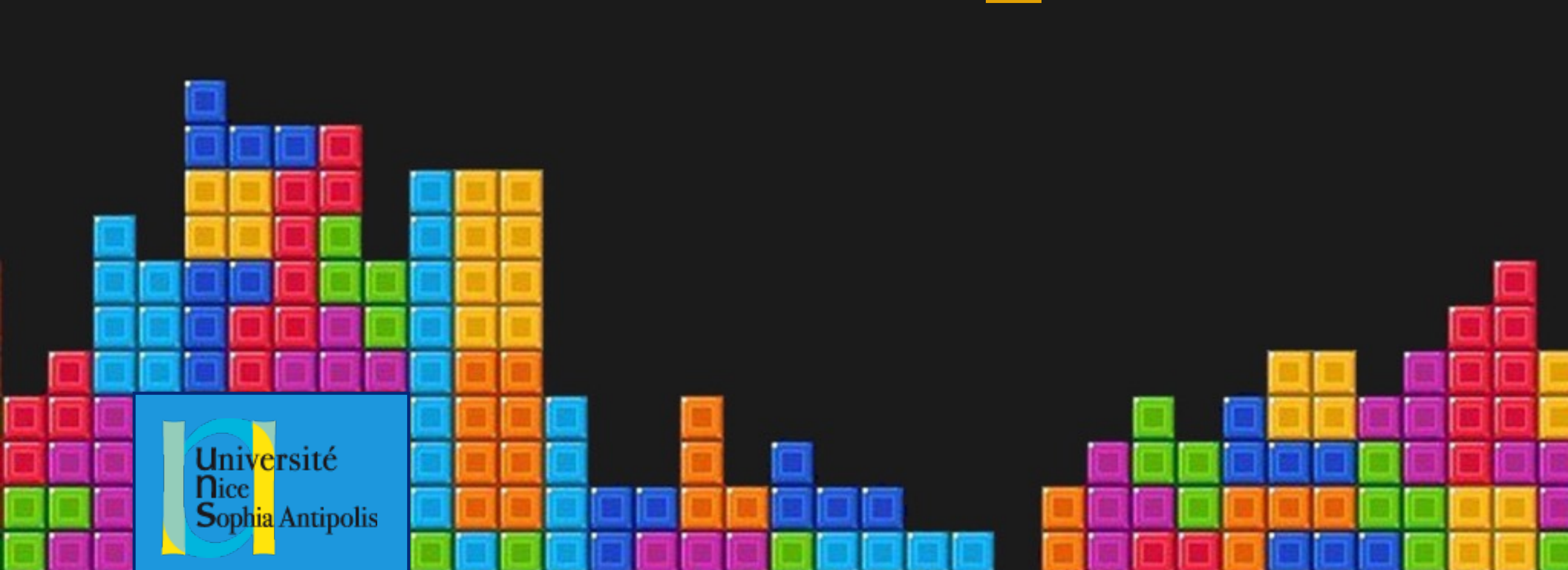
Resource management in IaaS cloud

Fabien Hermenier



where to place the VMs

?

how much to allocate

1 What can a resource manager do for you

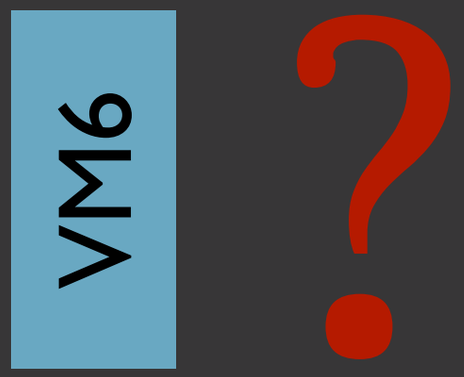
2 Models of VM scheduler

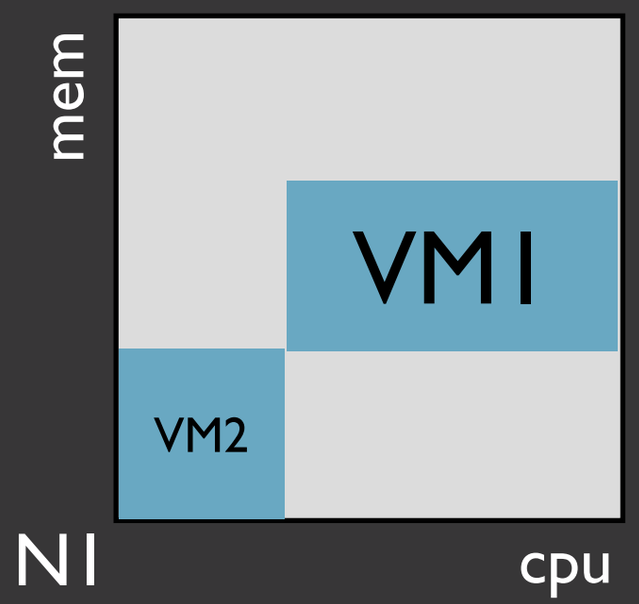
3 Implementing VM schedulers

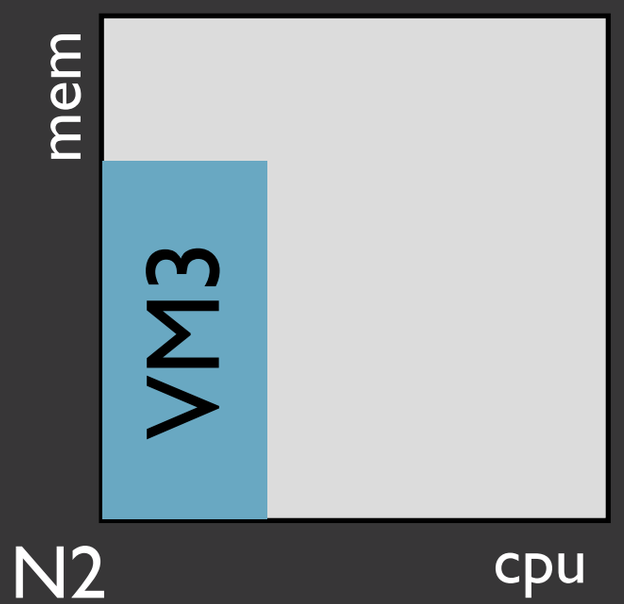
1 What can a resource manager do for you

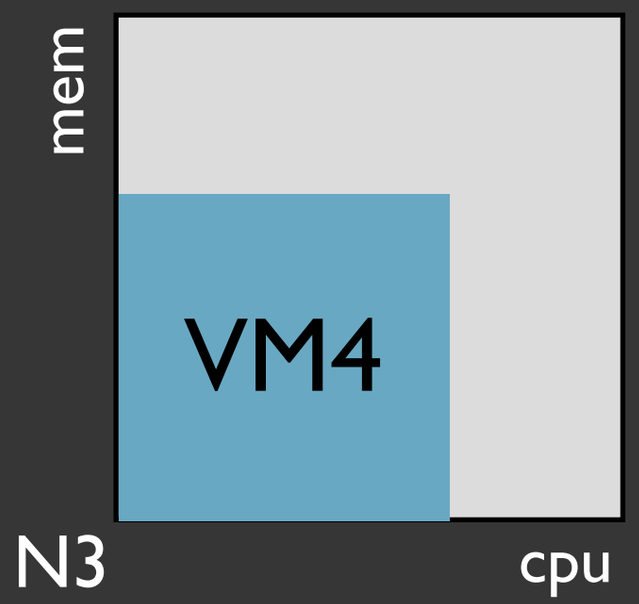
provide the awaited Quality of Service
address the management objectives

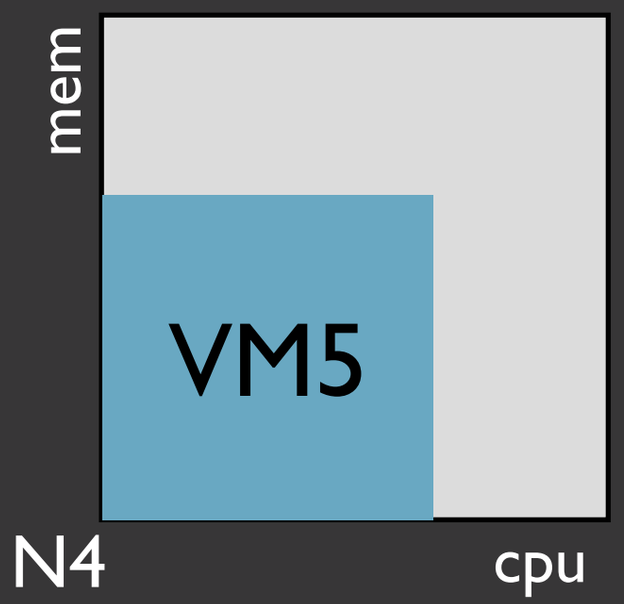
the RM should solve that



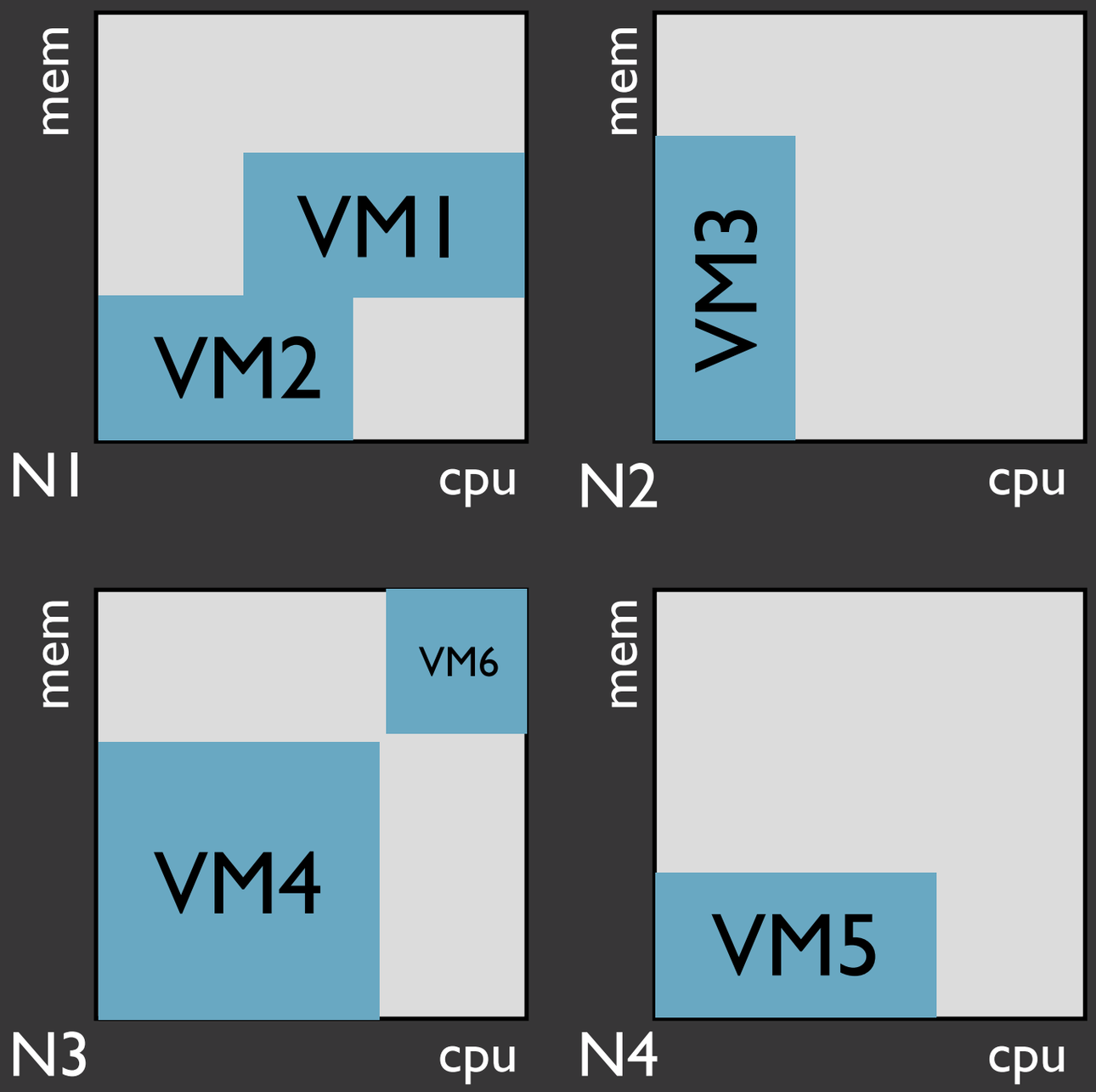








the RM should prevent that



Service Level Agreement

a contract where a service is formally defined

performance indicator
MTTR
MTBF
availability (MTBF/MTTR + MTBF)
pricing
penalties
…

Google Cloud Platform

Monthly uptime percentage	Percentage of monthly bill for the respective Covered Service which does not meet SLA that will be credited to future monthly bills of Customer
99.00% - < 99.95%	10%
95.00% - < 99.00%	25%
< 95.00%	50%

uptime as the only
Key Performance Indicator (KPI) ?

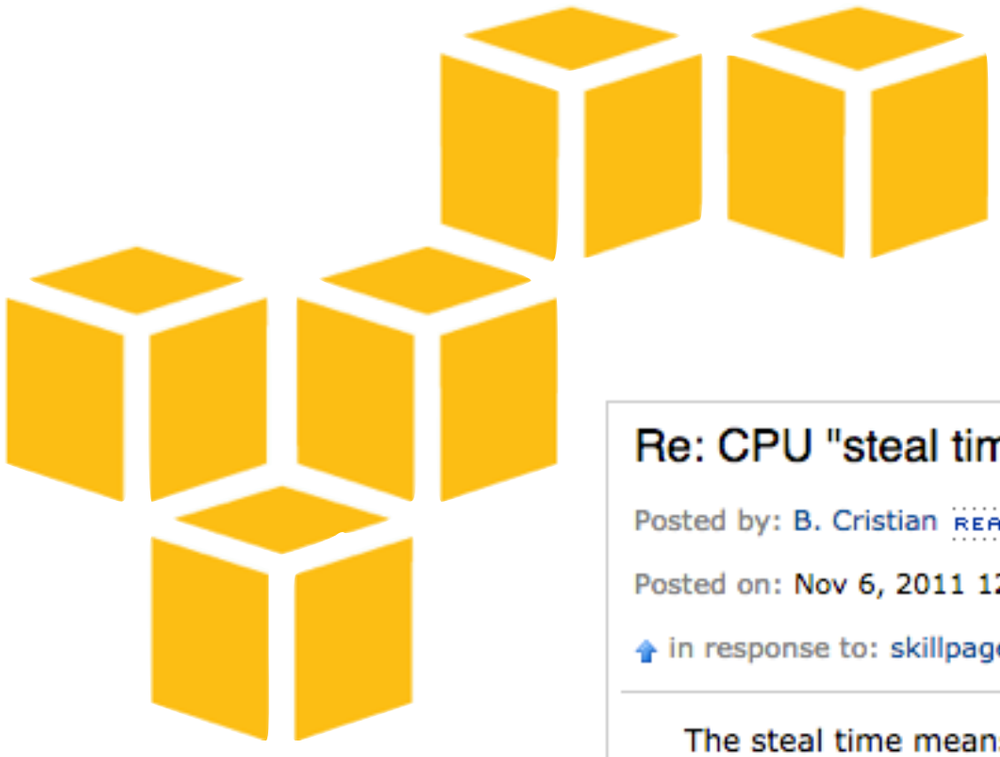
Cloud Performance SLAs

What customers want

guaranteed capacities (CPU, memory, bw)
guaranteed latencies/throughput (network, load balancer, disk)

What providers give

-



Re: CPU "steal time" - is Netflix right?

Reply

Posted by: B. Cristian REAL NAME™

Posted on: Nov 6, 2011 12:32 AM

in response to: skillpages

> The steal time means you're trying to go over your allocated resources. AWS doesn't give you a dedicated amount of resources, it gives you access to more, so that when the host machine isn't under heavy load you can use more resources, which would otherwise be wasted.

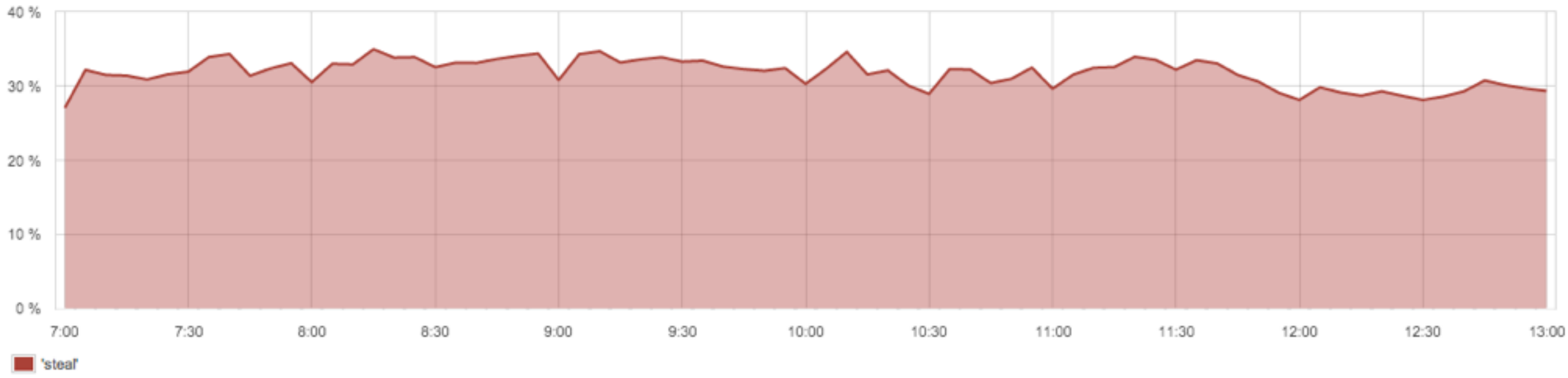
auto granularity | From: 2013.04.19 07: To: 2013.04.19 13: | (GMT-5:00) America/New York | 30m 1h 6h 1d 2d 1w 30d 60d

Memory Details | Load | Swap

CPU Details - 2013.04.19 07:00 to 2013.04.19 13:00

hide extended chart | stacked

'user' | 'system' | 'wait' | 'interruption' | 'soft interruption' | 'nice' | 'steal' | 'idle'



the objective

provider side

min(x) or *max(x)*

atomic objectives

$$min(\textit{penalties})$$

$$min(\textit{Total Cost Ownership})$$

$$min(\textit{unbalance})$$

...

composite objectives

using weights

$$min(\alpha x + \beta y)$$

How to estimate coefficients ?

useful to model sth. you don't understand ?

$$min(\alpha\ TCO + \beta\ VIOLATIONS)$$

€ as a common quantifier:

$$max(REVENUES)$$

?

Should a client ask for an objective

?

Should a client ask for an objective

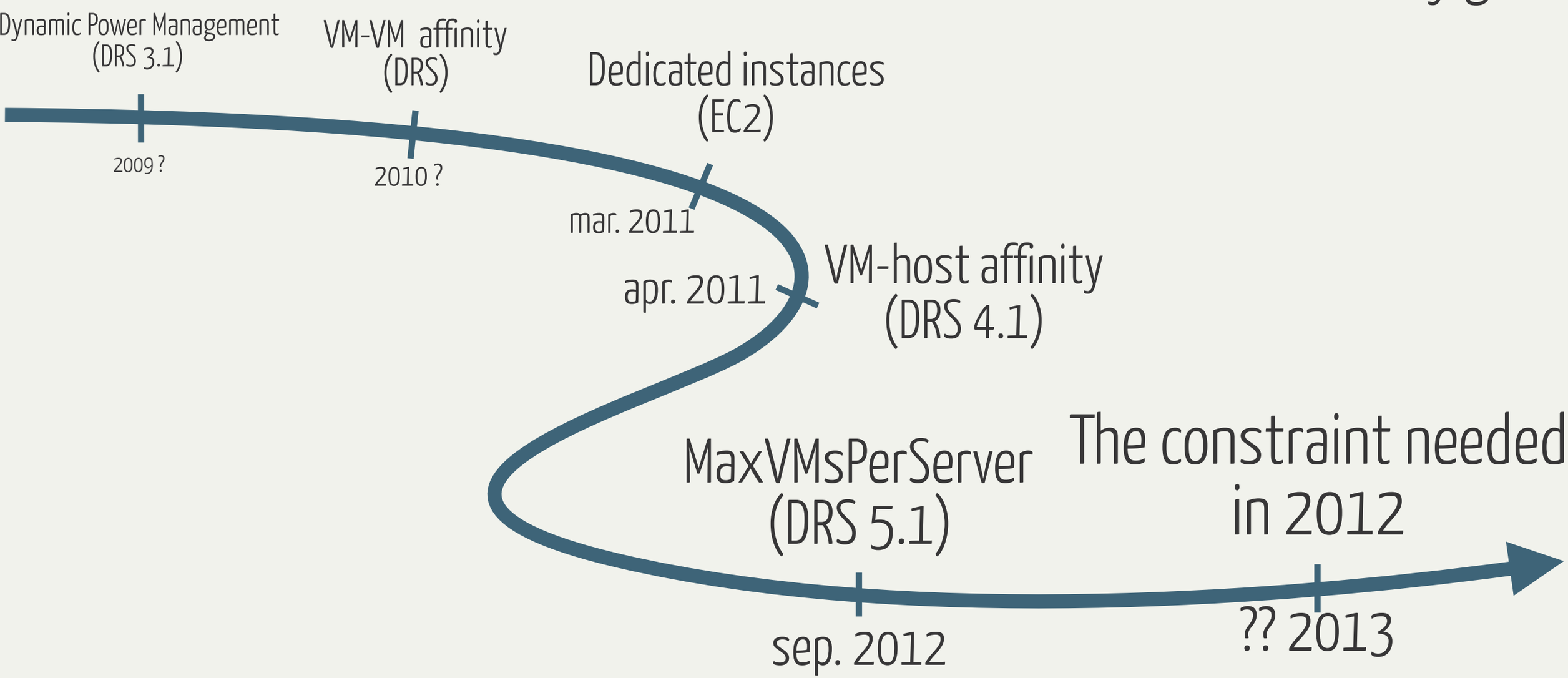
no if the provider cannot prove it is achieved

one can check the latency is below a threshold

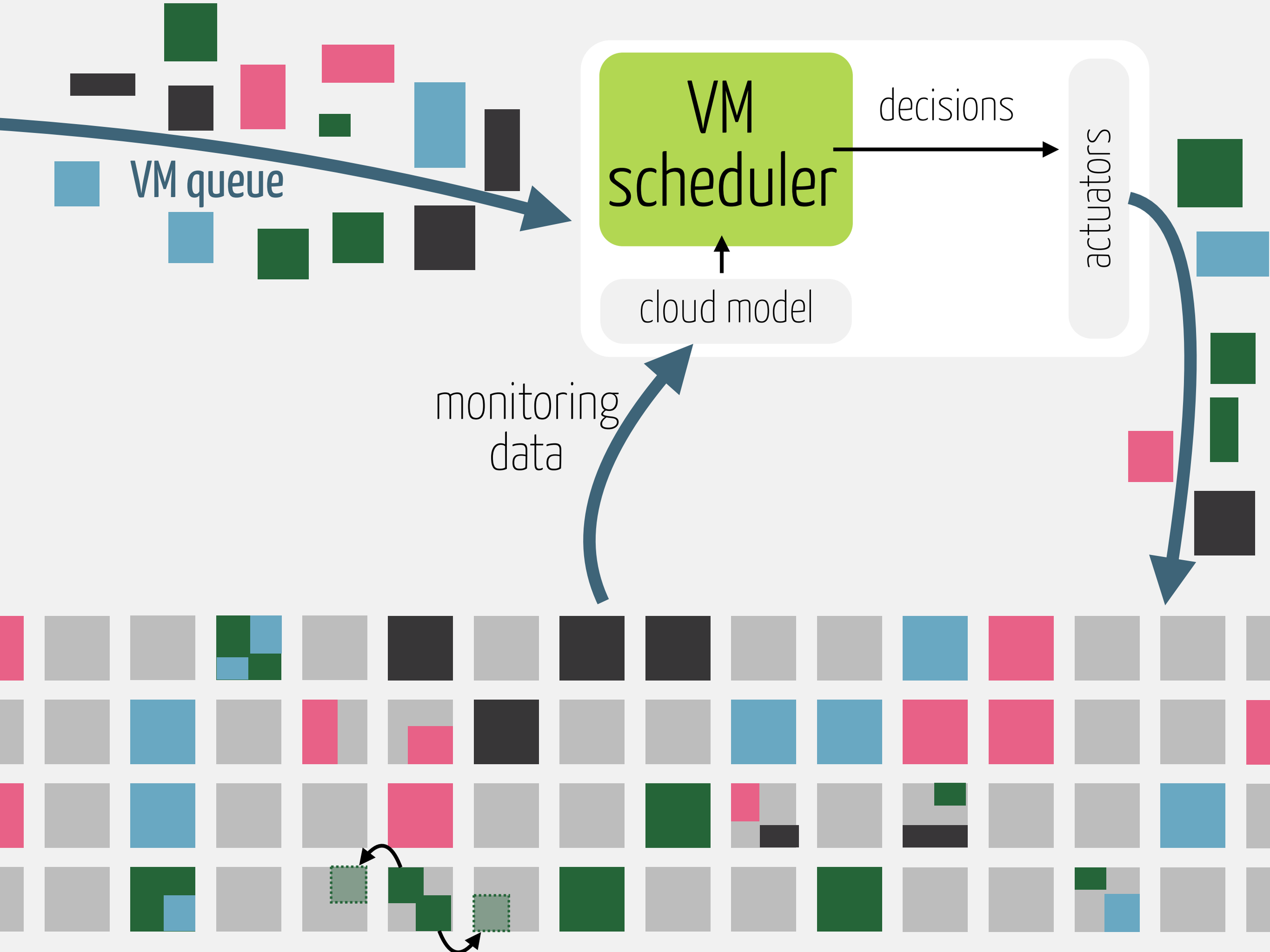
proving a latency is minimal ...

SLOs and objectives are evolving

there is no holy grail



2 Models of VM schedulers

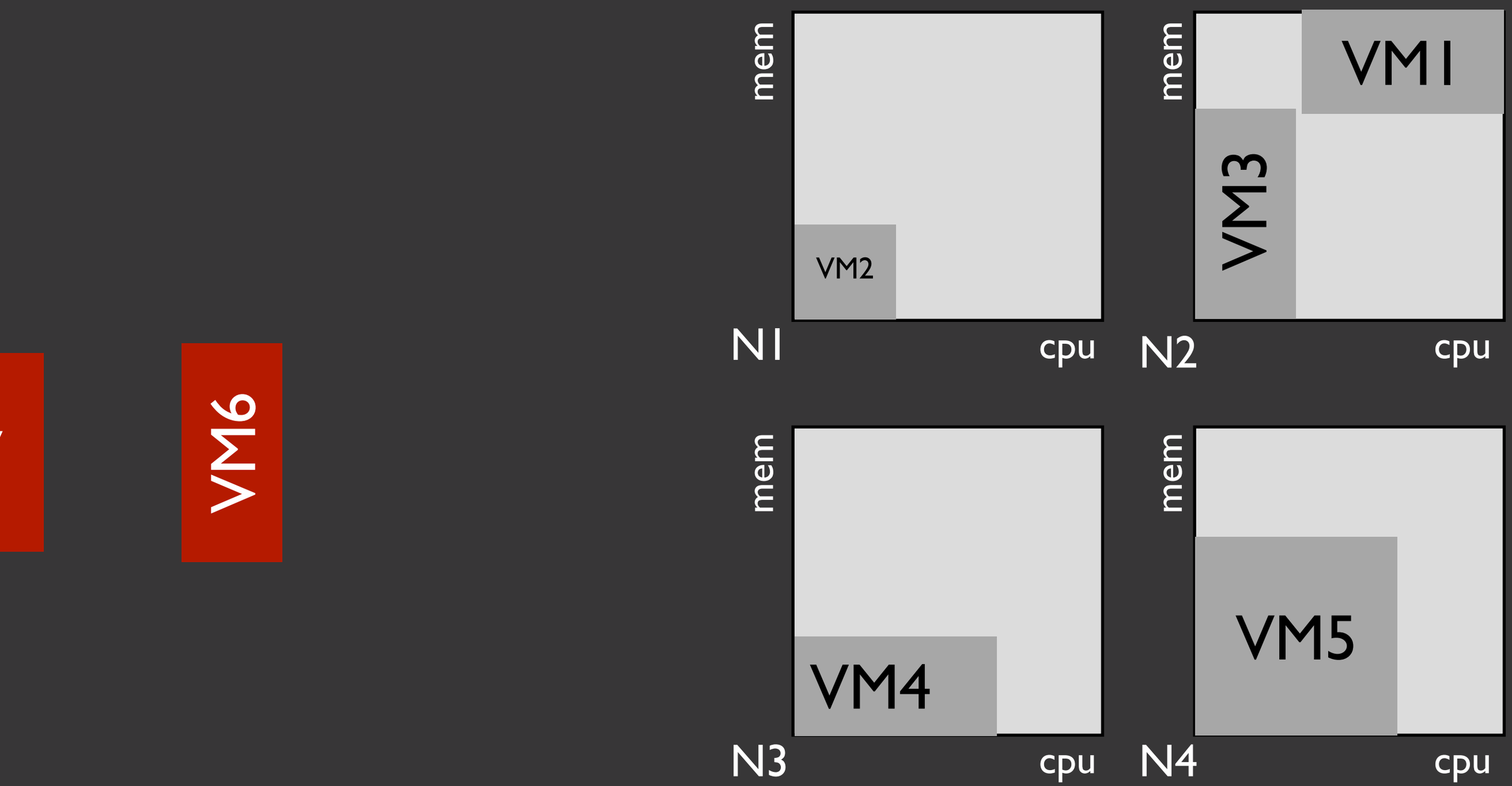

VM queue
VM scheduler
decisions
actuators
cloud model
monitoring data

scheduling models

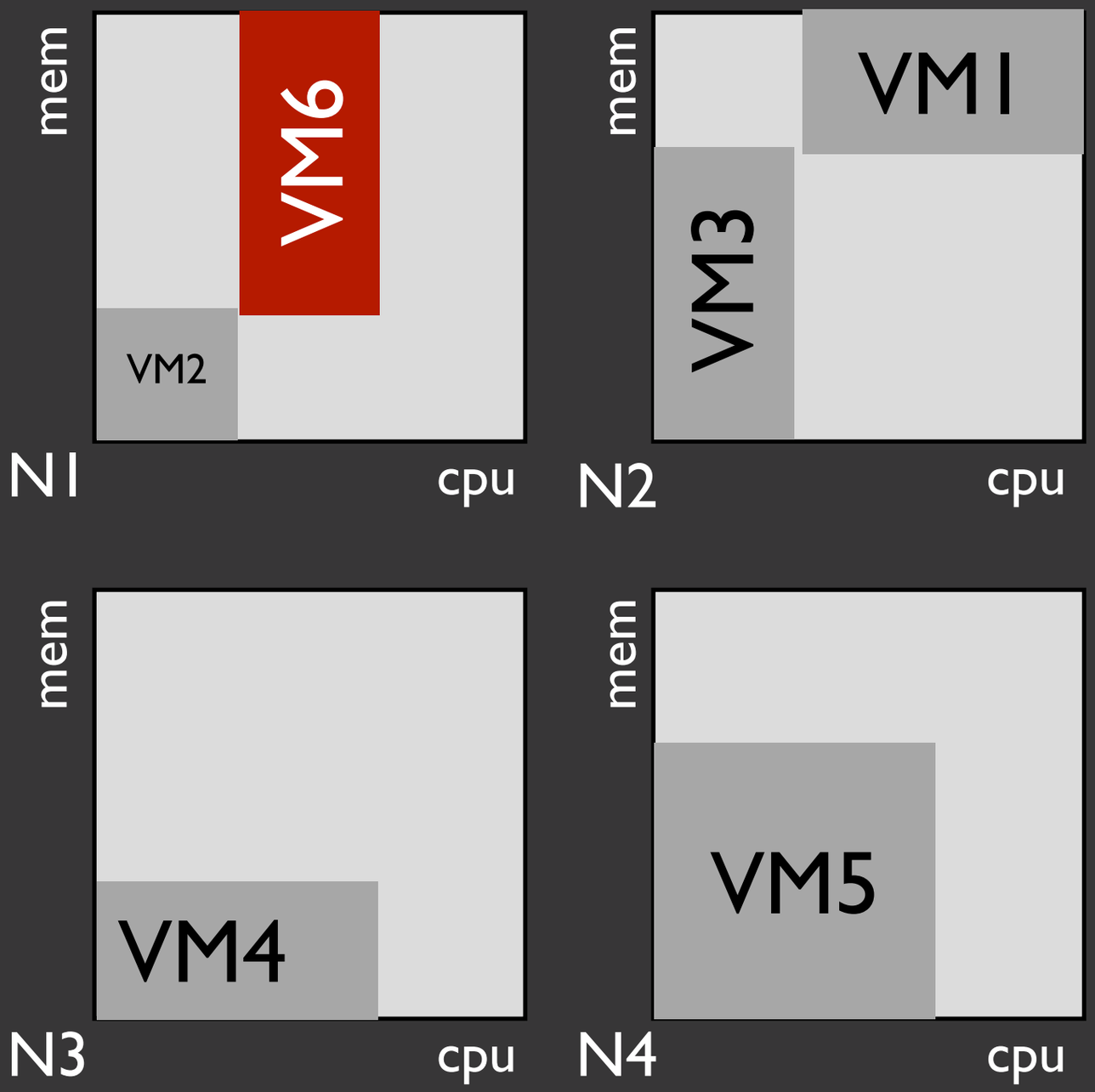
static
dynamic
schedulers

static
dynamic
resource allocation

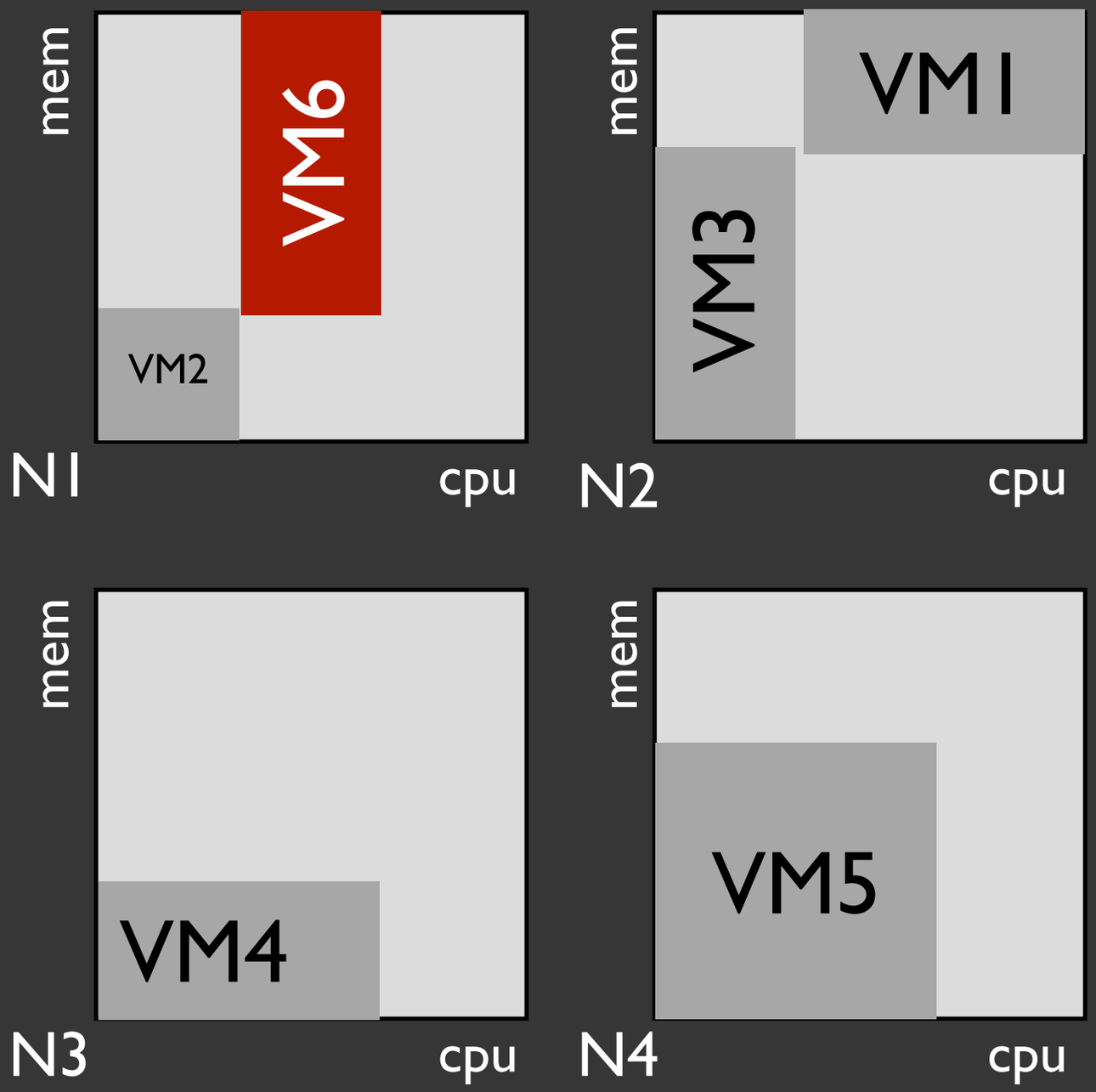
static schedulers



static schedulers



static schedulers



VM7

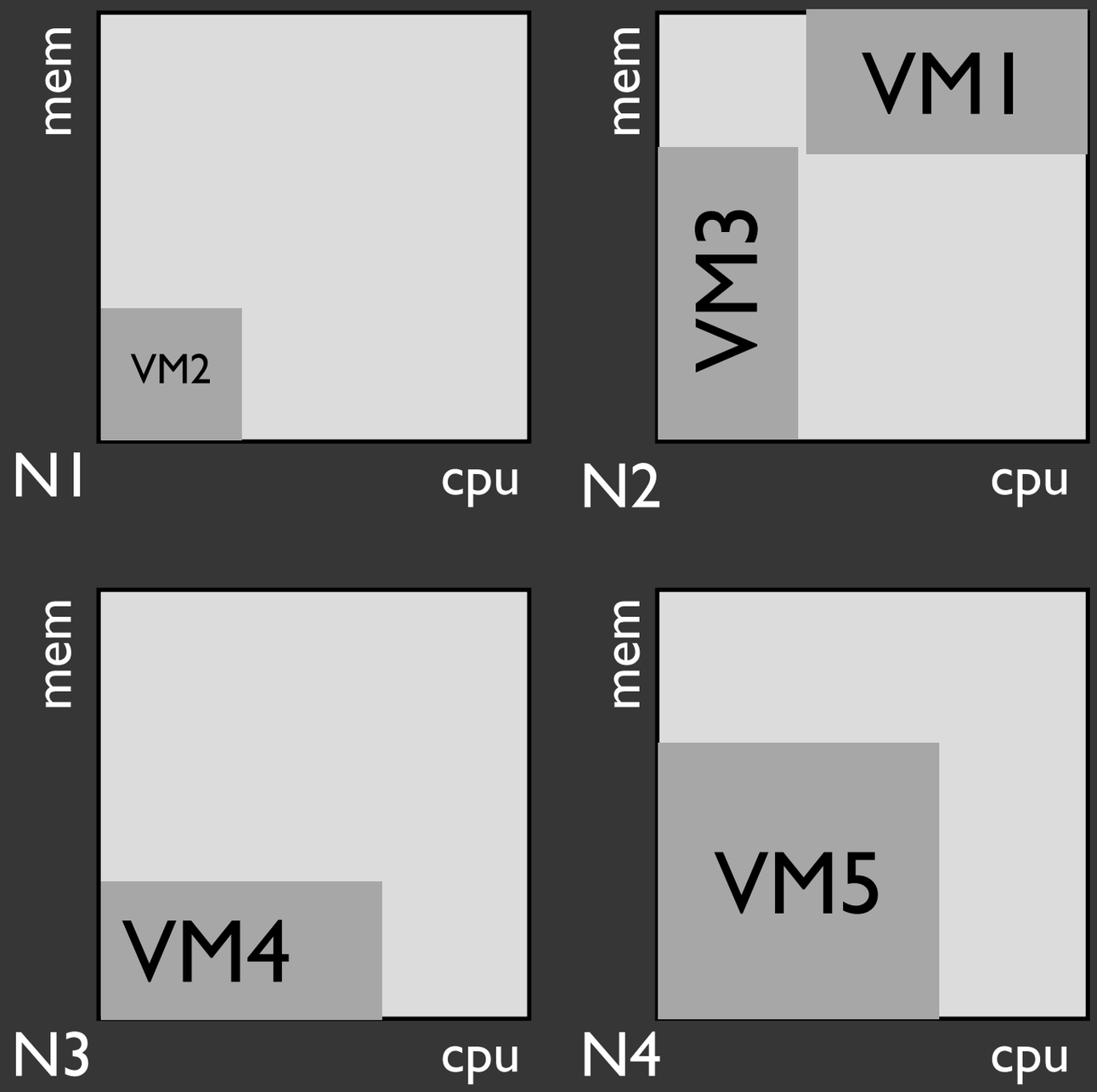
Combinatorial problem !

past decisions impact the future ones

static schedulers

buffering might help

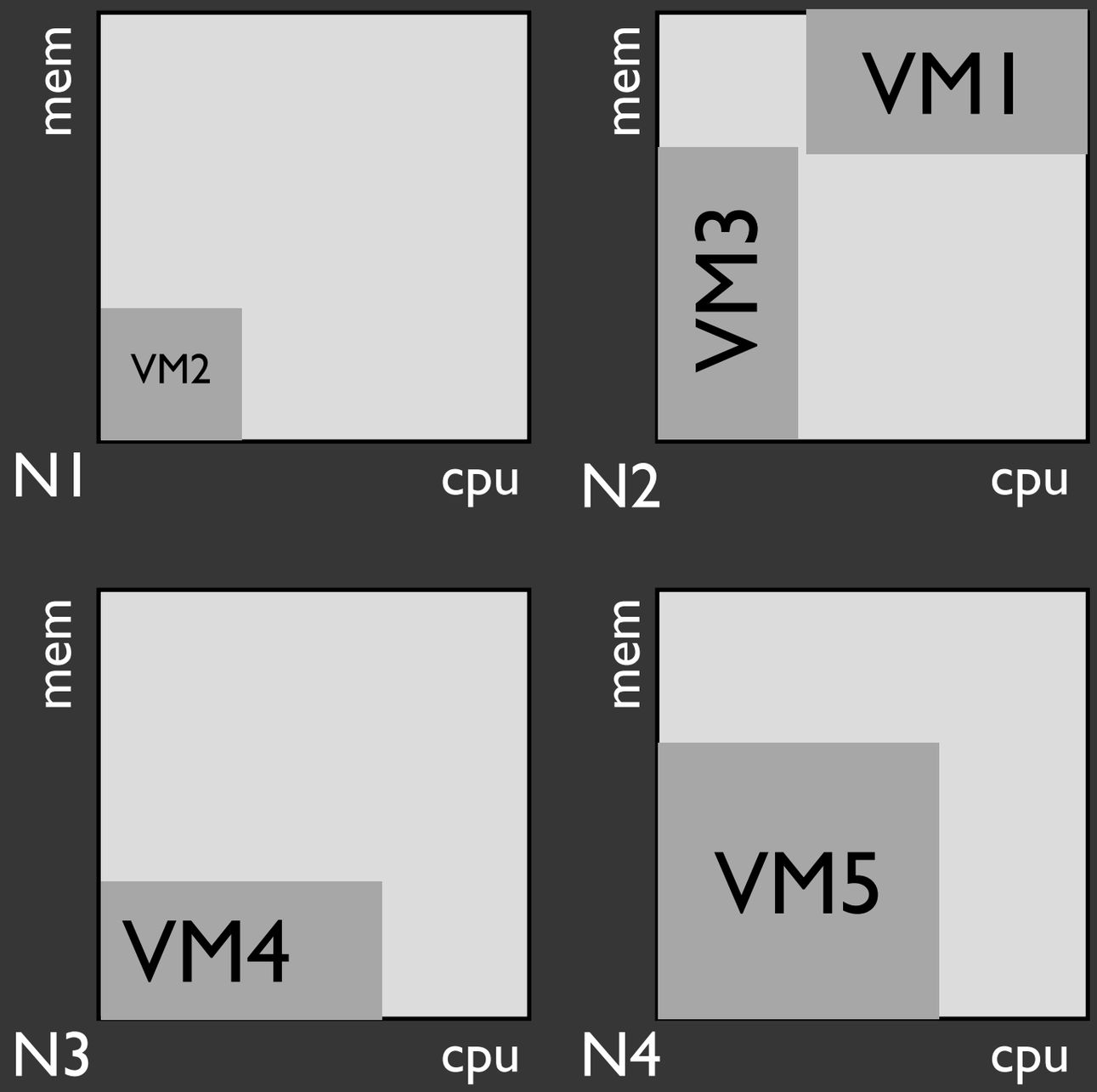
VM6



static schedulers

buffering might help

VM6



static schedulers

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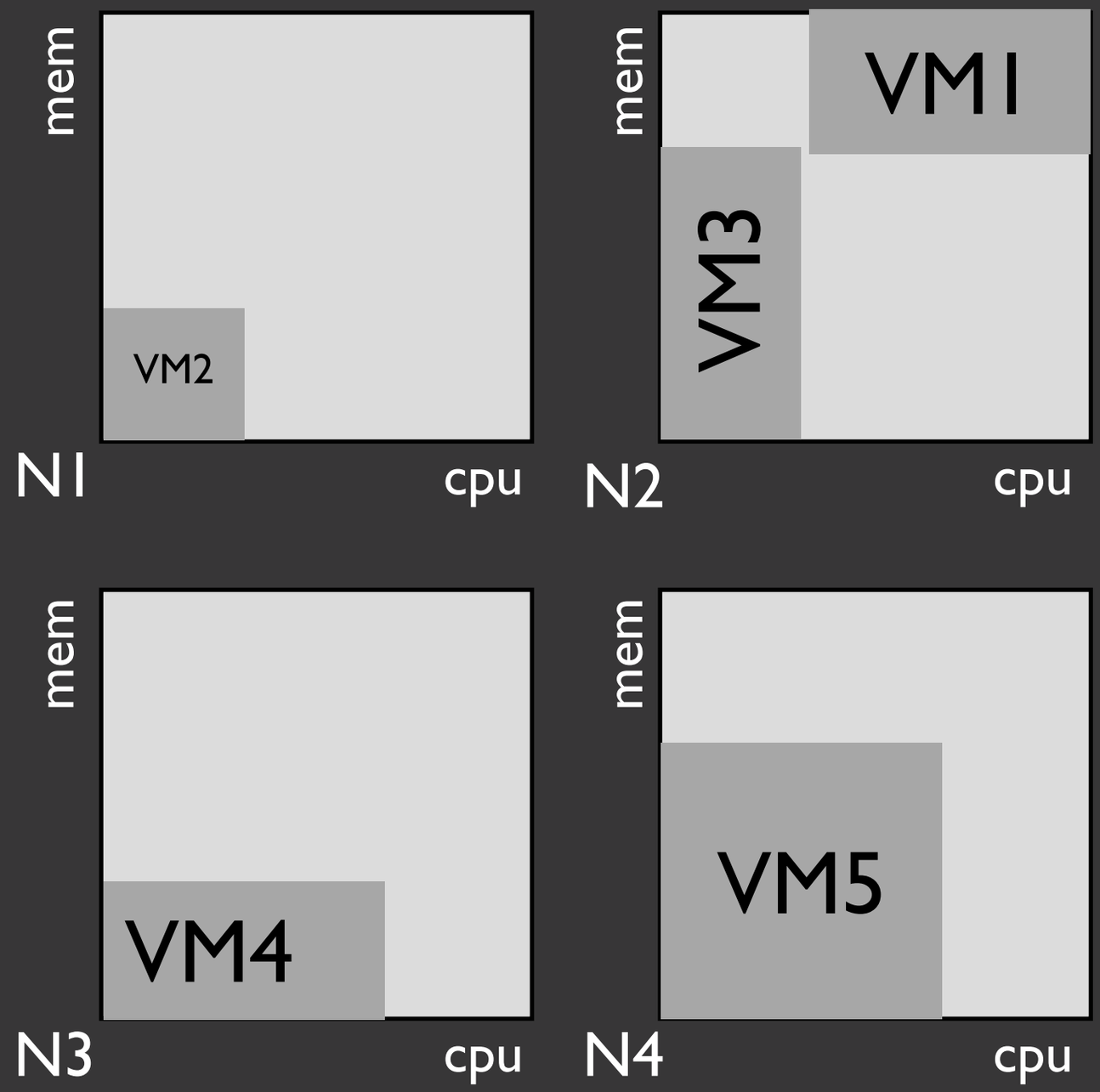

static schedulers

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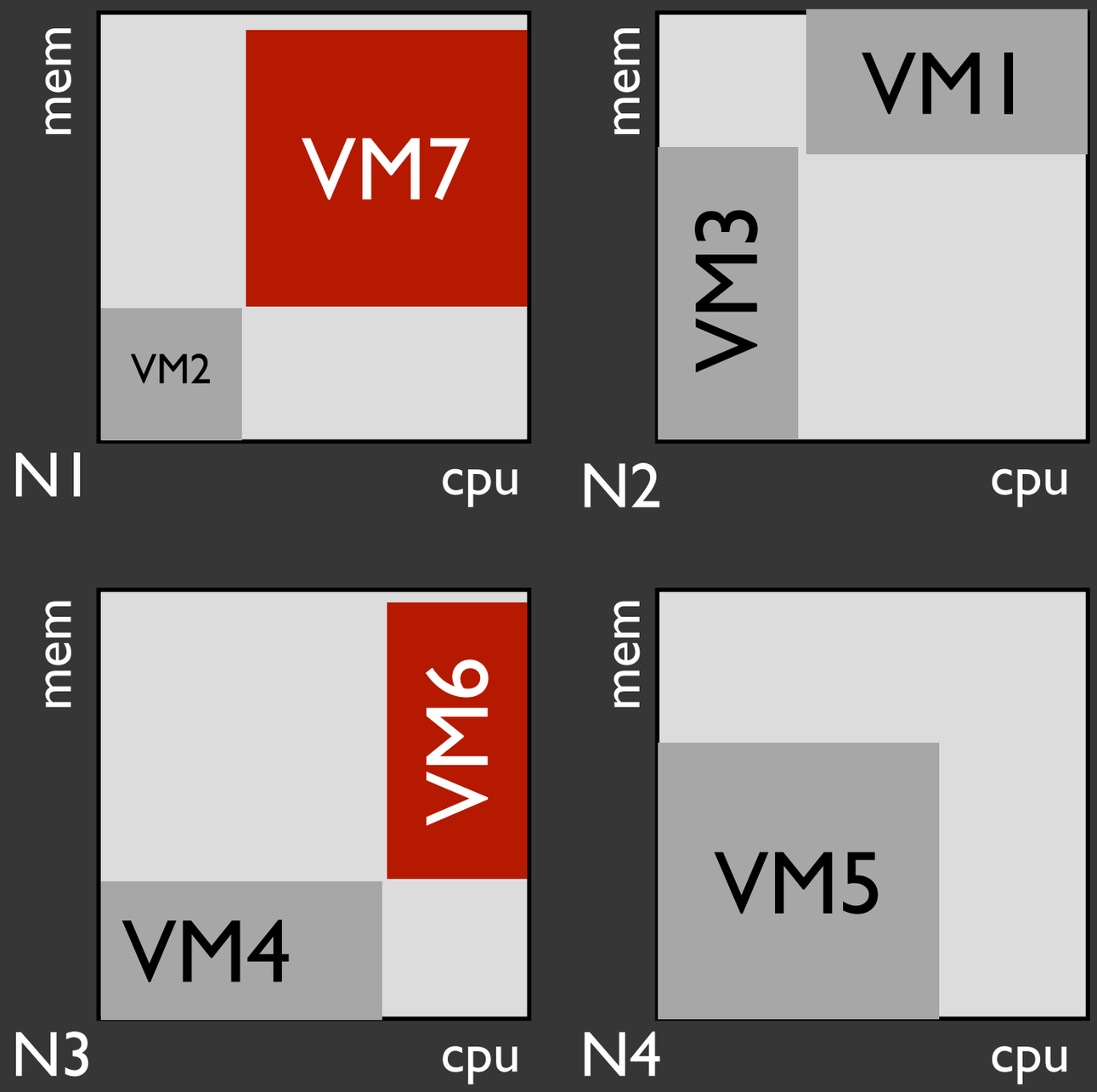
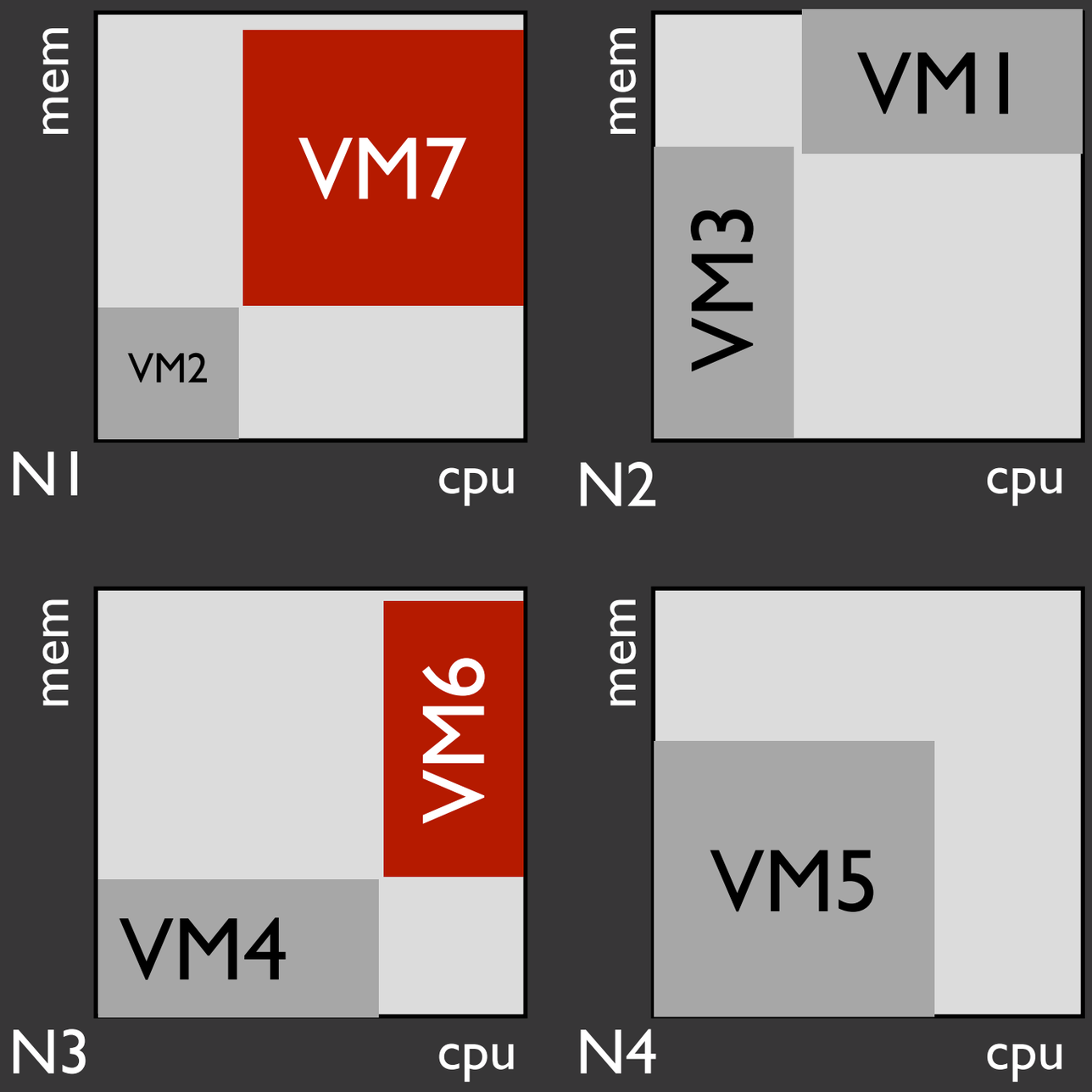


static schedulers

buffering might help

/!\ incoming rate starvation



static schedulers

manipulate the VM queue only
react on VM arrival

static schedulers

pros

easy to model
simple standard actions
manage a few elements

static schedulers

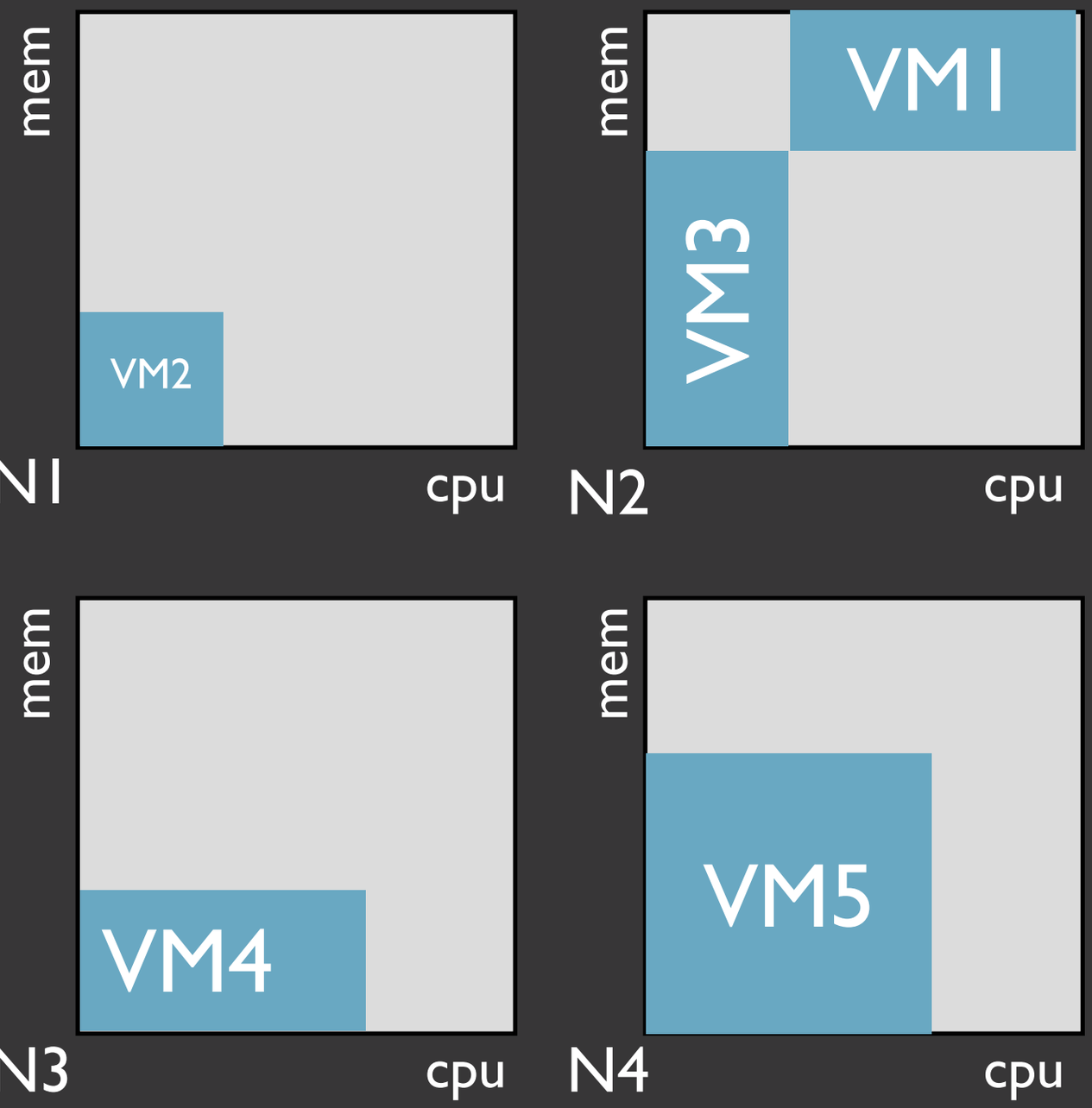
cons

hard to perform fine grain optimisation

dynamic schedulers

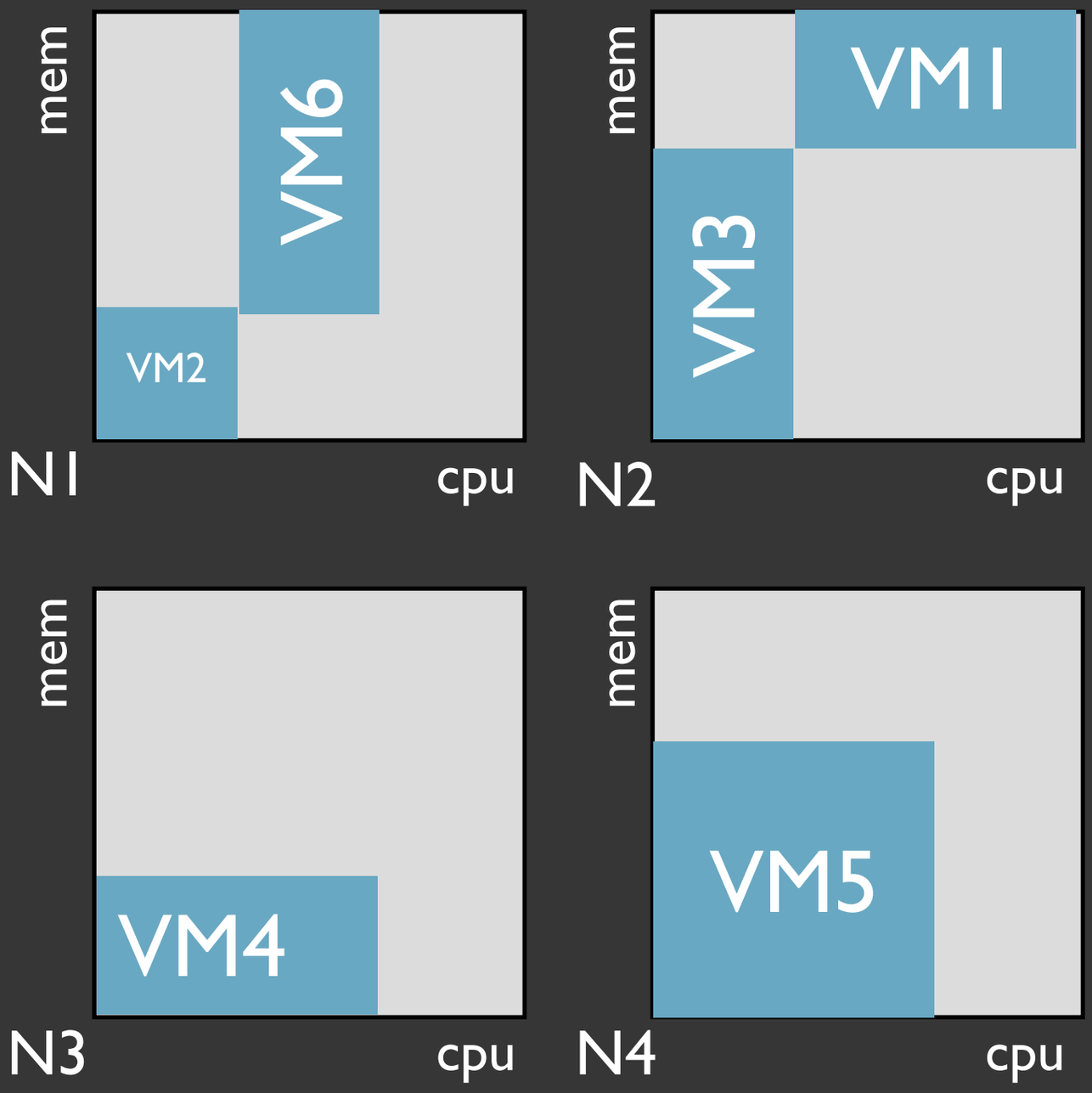
consider every VMs

VM6



dynamic schedulers

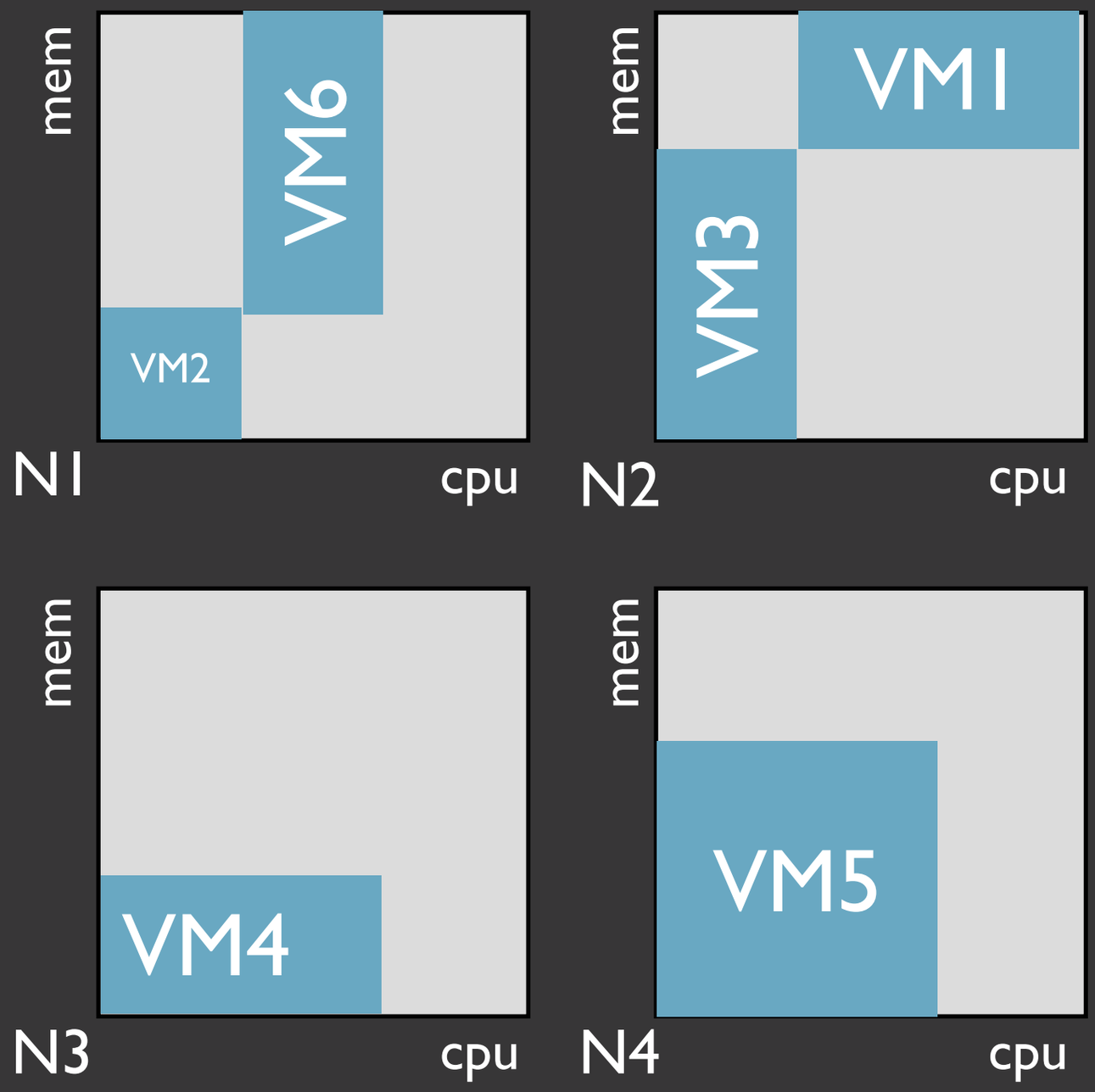
consider every VMs



dynamic schedulers

consider every VMs

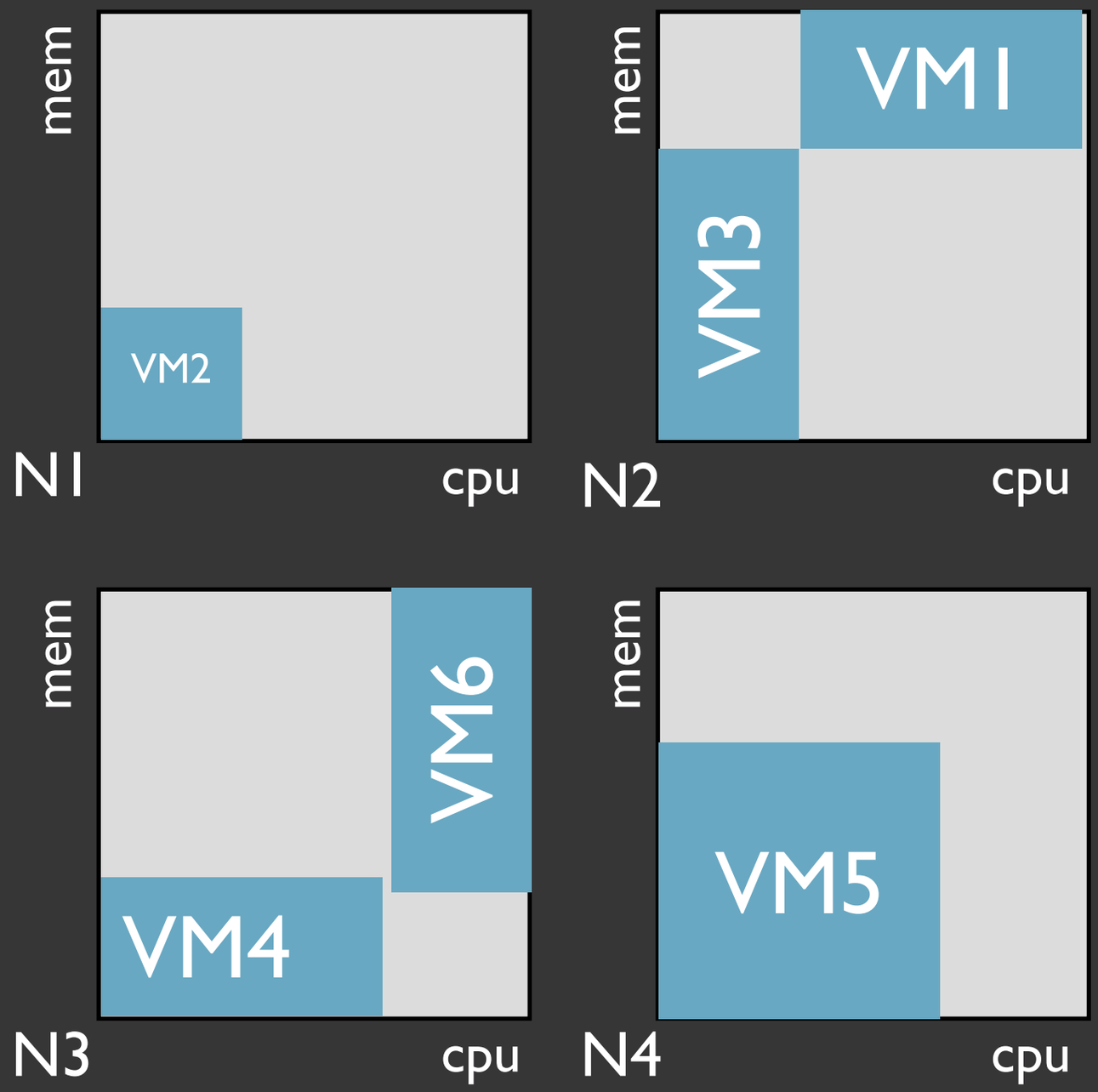
VM7



dynamic schedulers

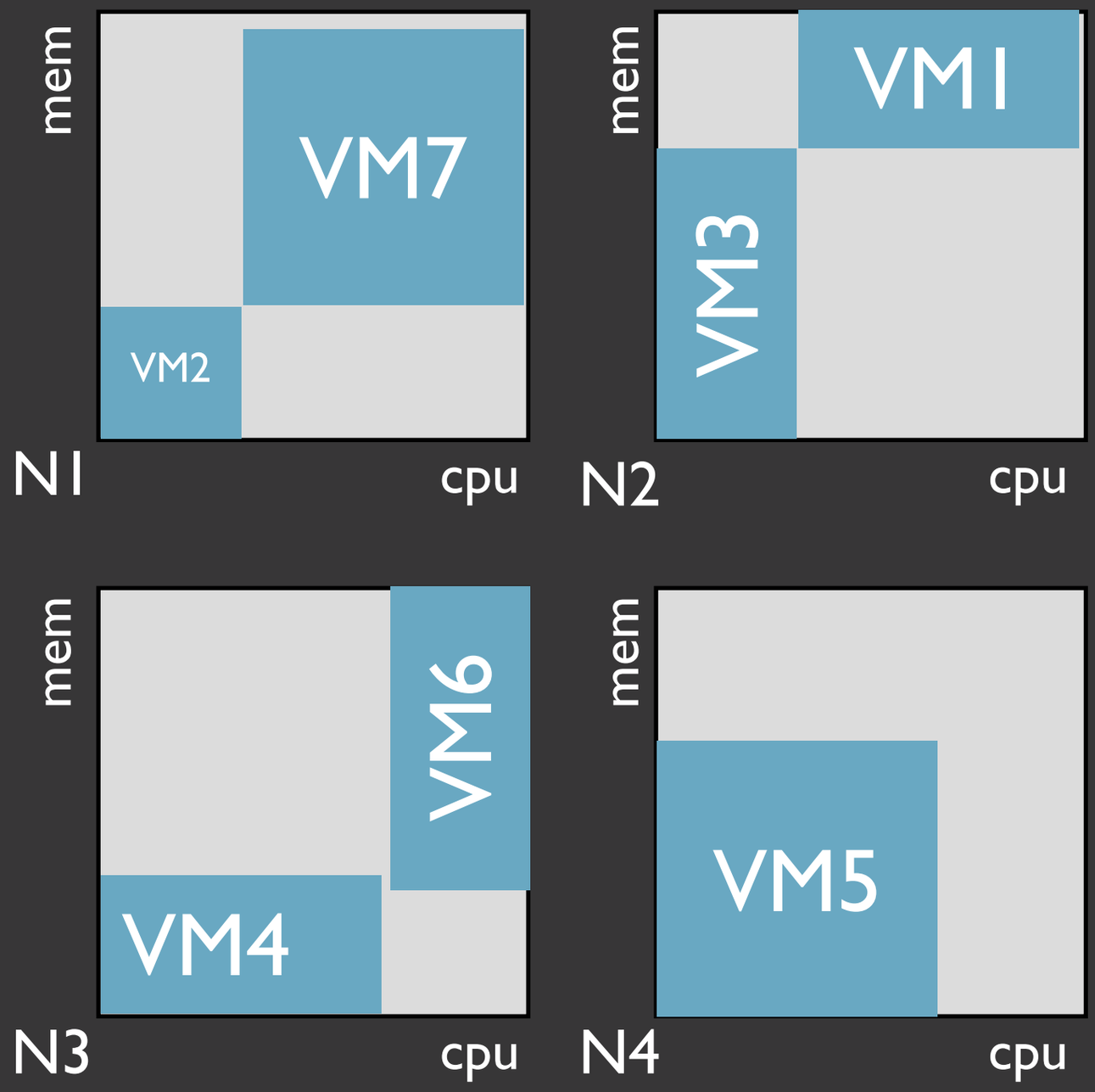
consider every VMs

VM7



dynamic schedulers

consider every VMs

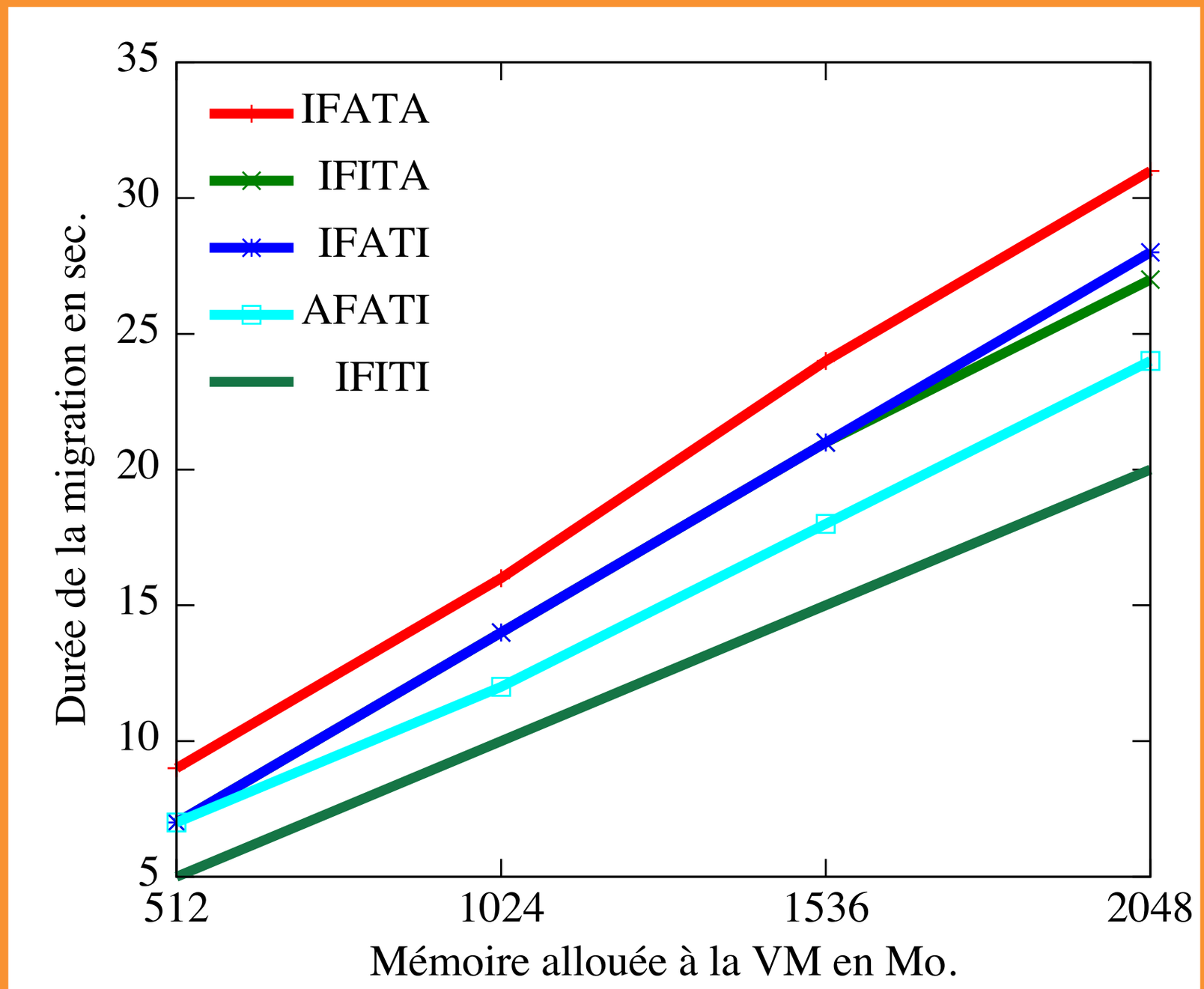


dynamic schedulers

manipulate the VM queue
reconfigure the schedule with migrations

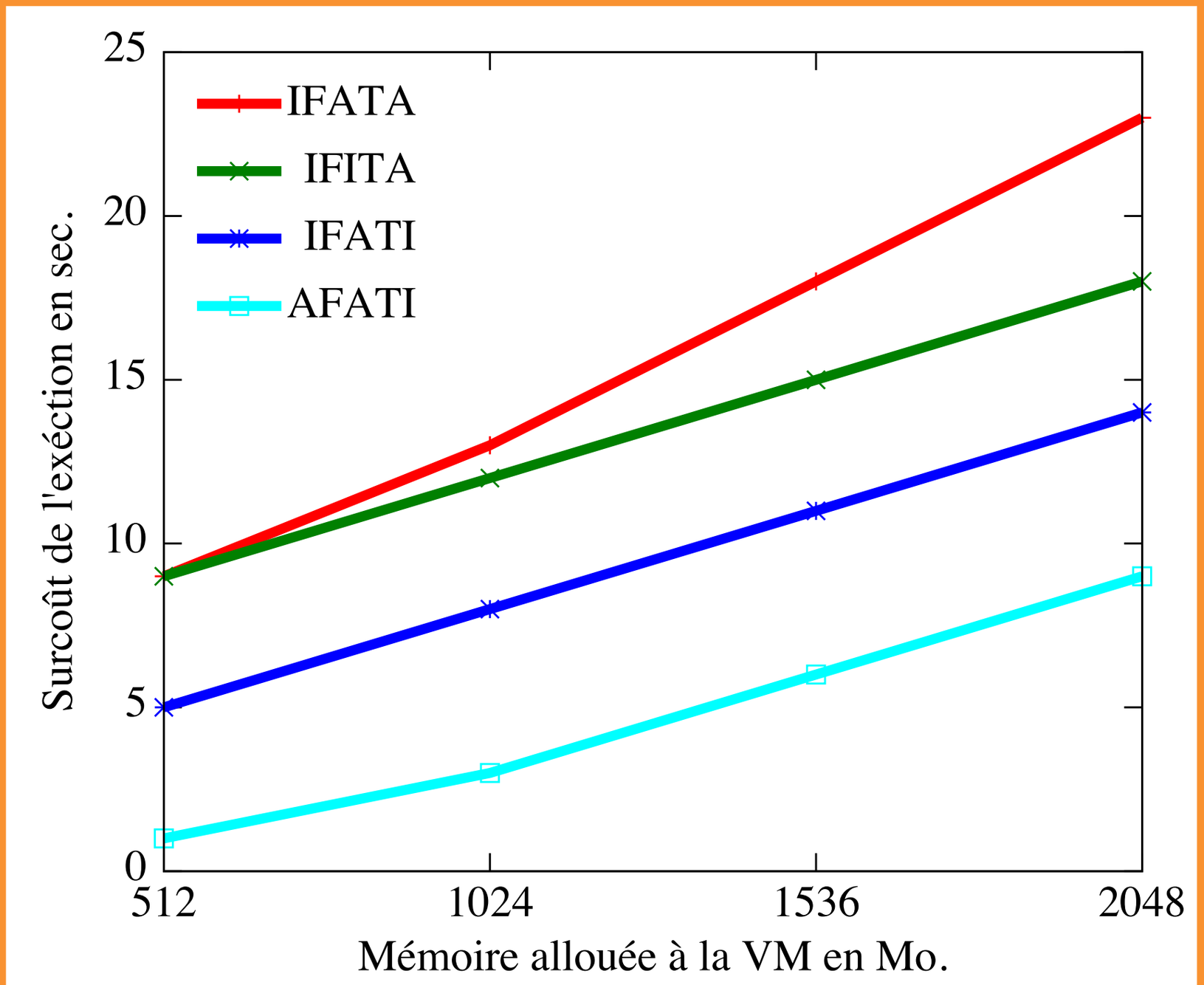
dynamic schedulers

a migration takes time



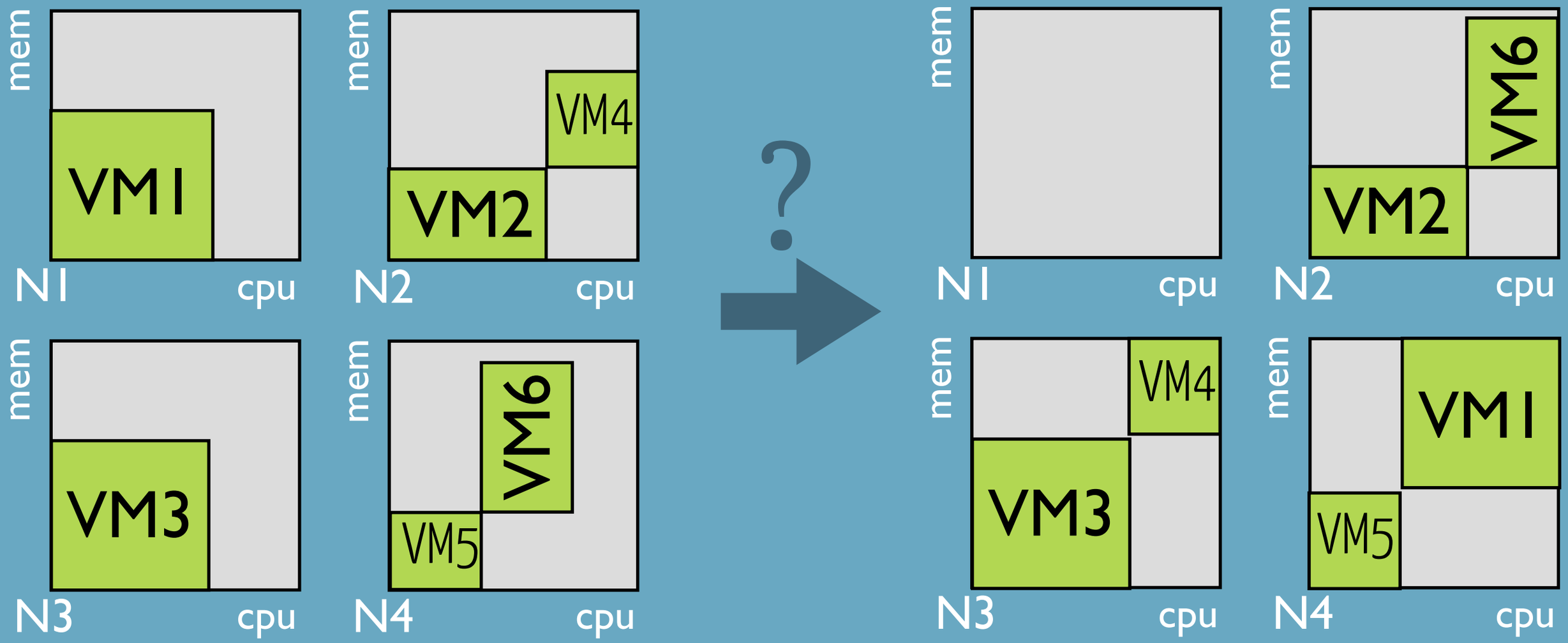
dynamic schedulers

a migration impacts performance



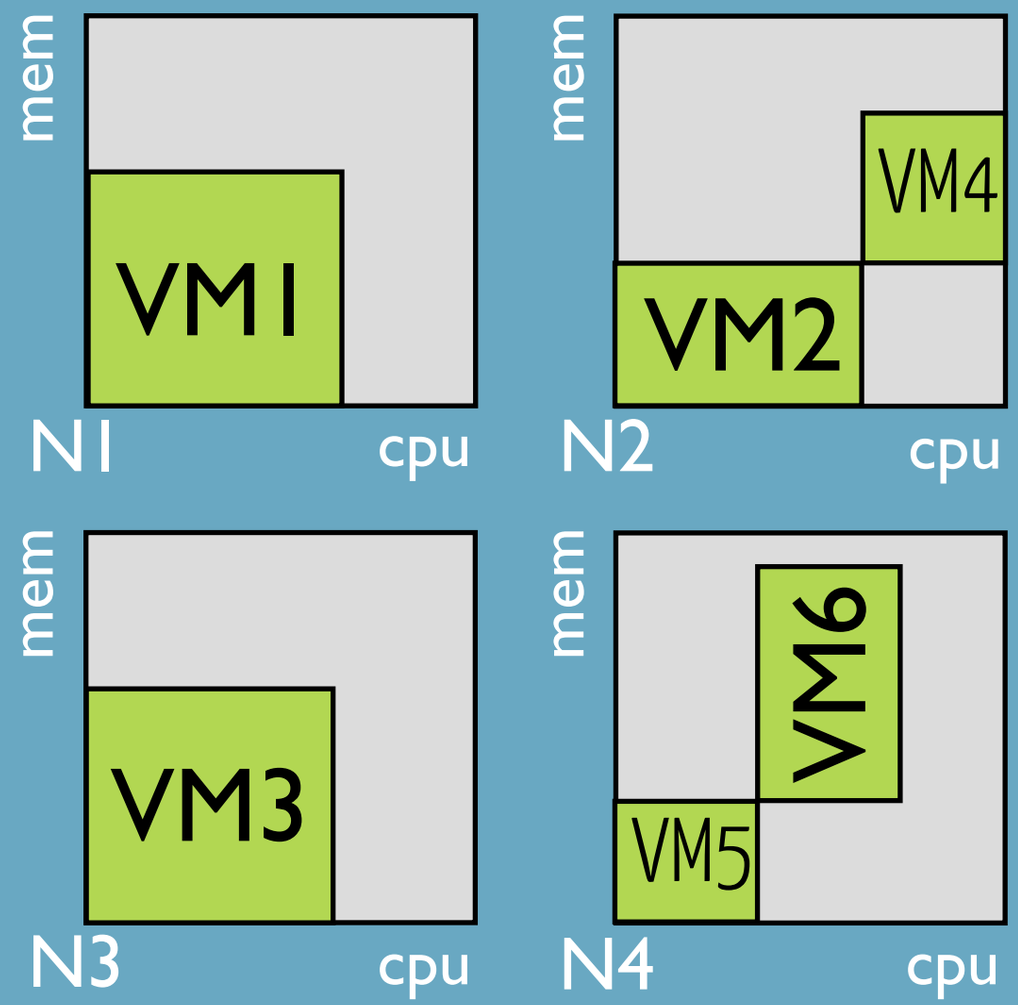
dynamic schedulers

dependency management



dynamic schedulers

dependency management



dynamic schedulers

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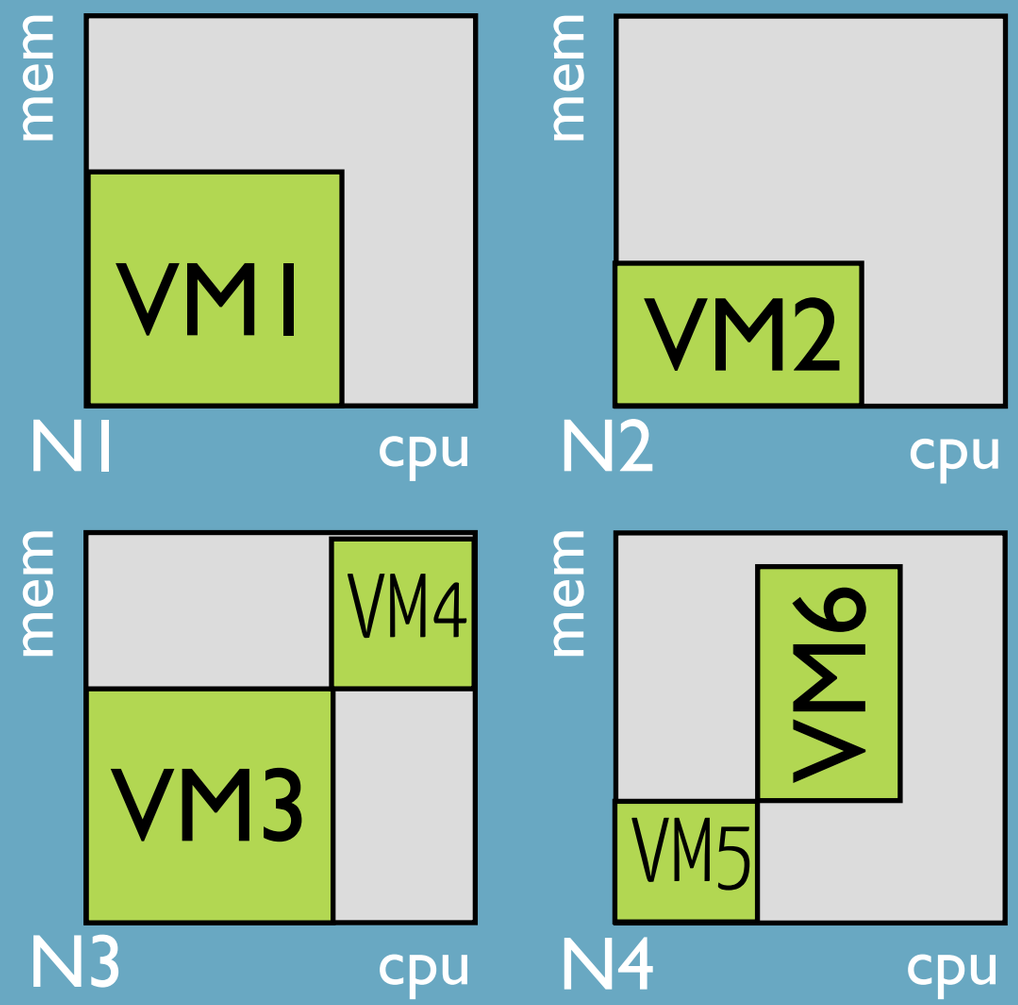
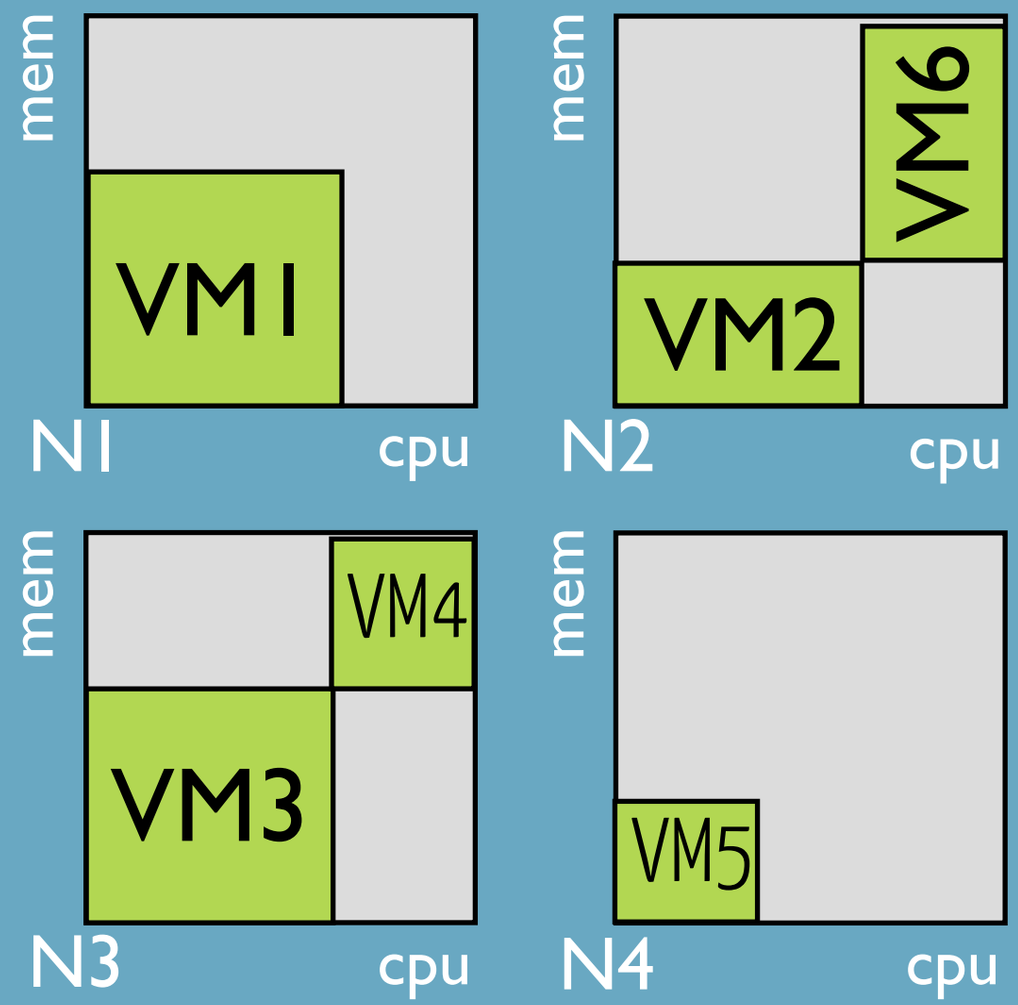


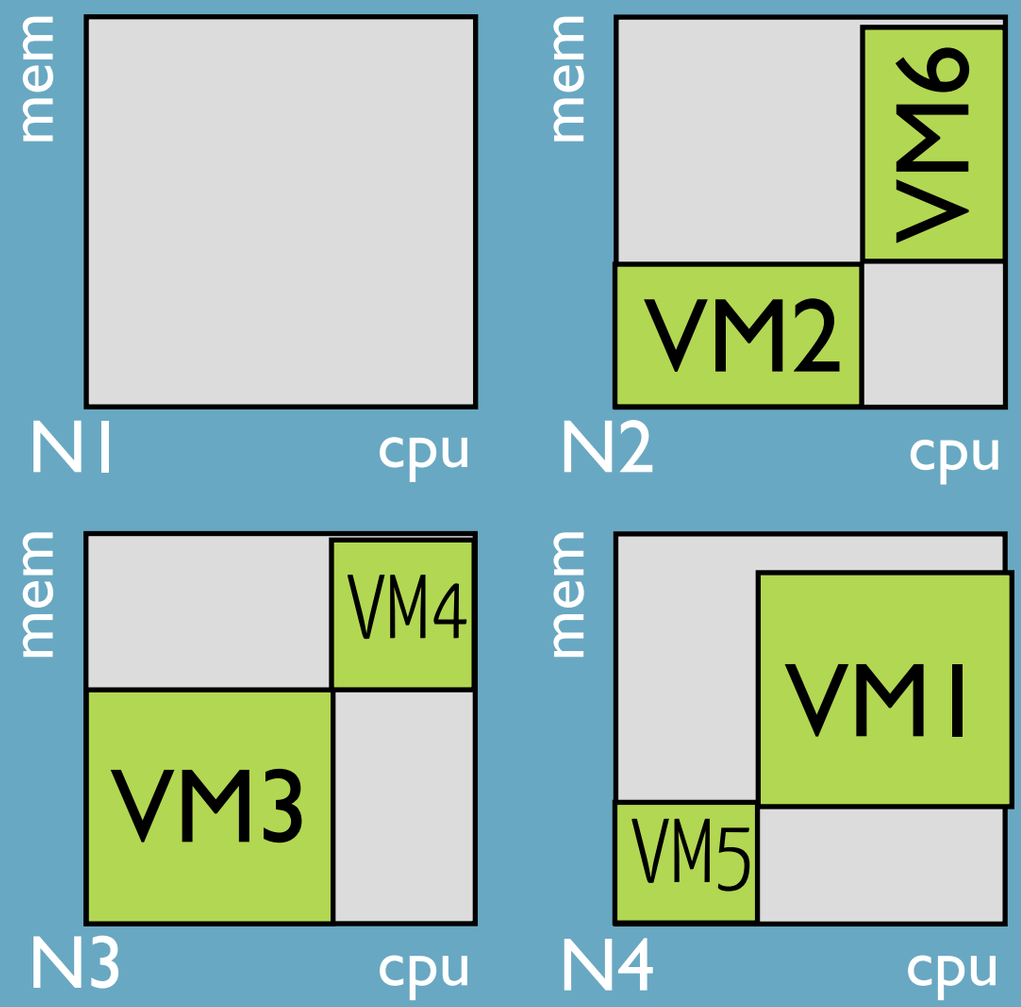
dynamic schedulers

dependency management



dynamic schedulers

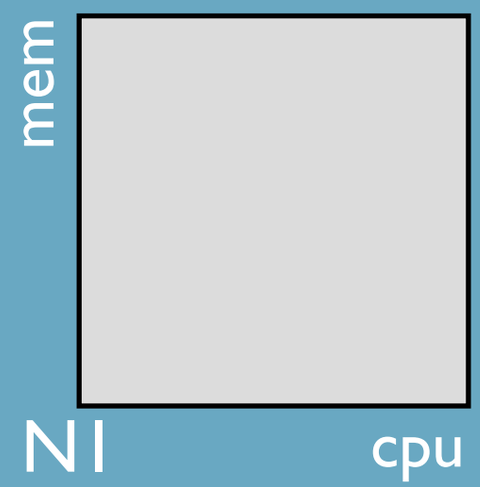
dependency management

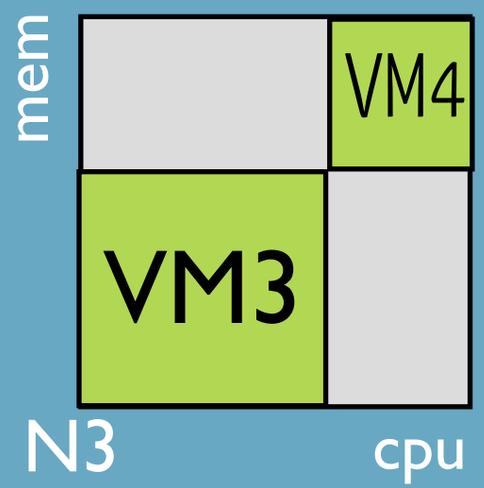


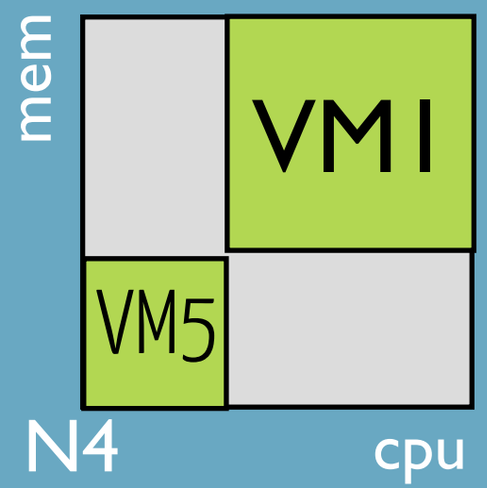
dynamic schedulers

cyclic dependencies

anti-affinity(VM3,VM4)
min(#onlineNodes)







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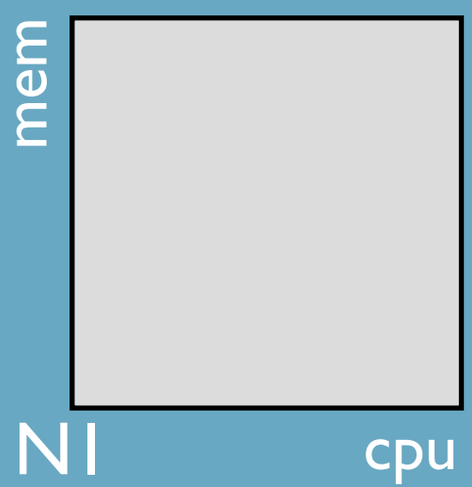
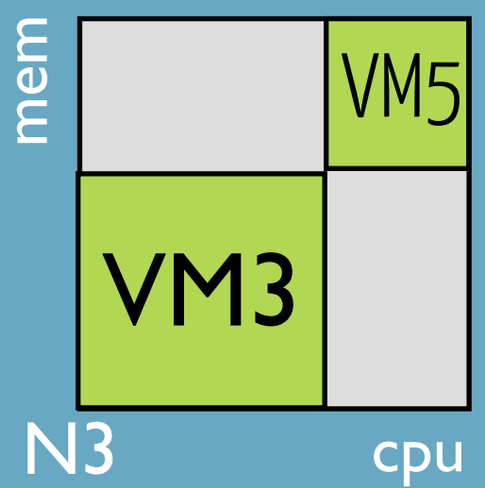
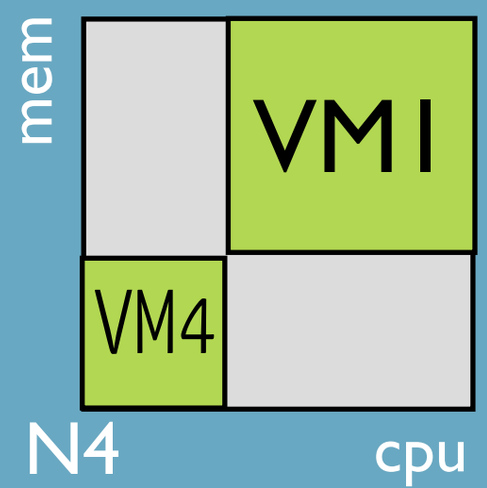
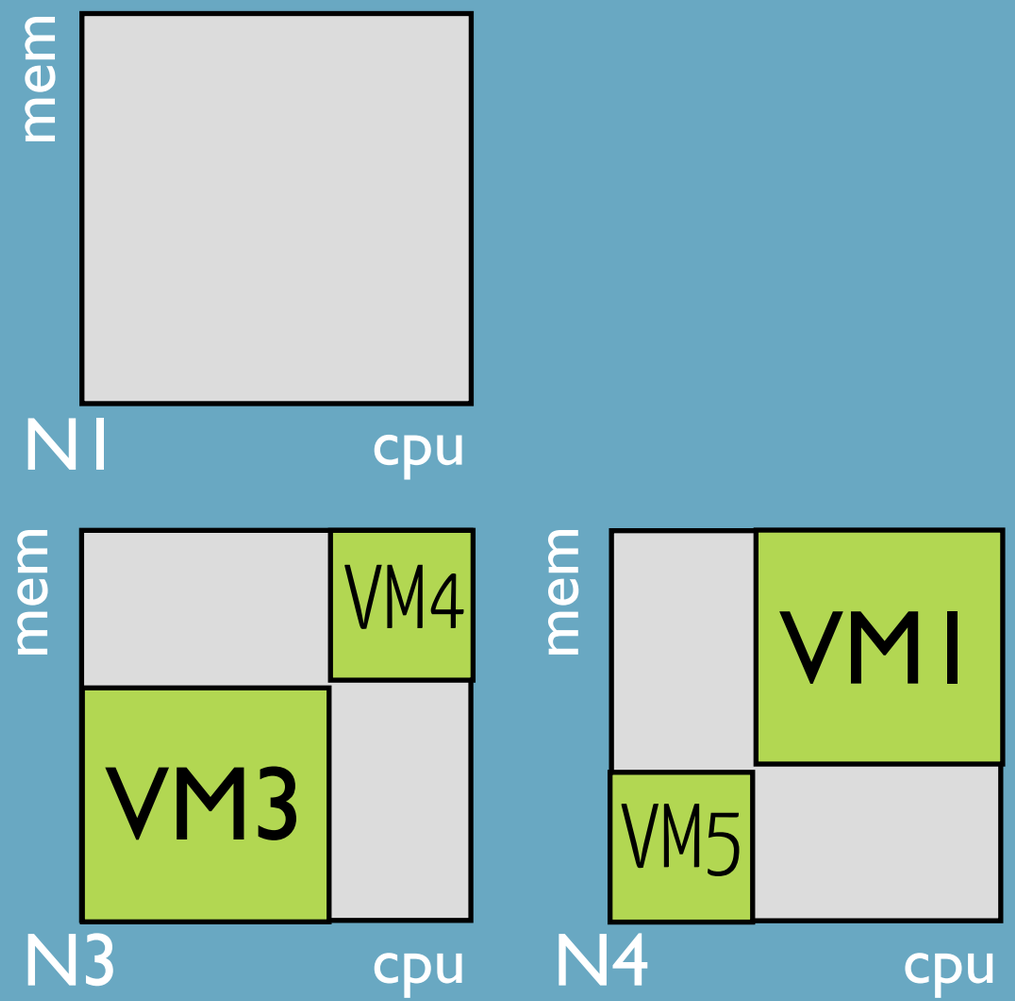






dynamic schedulers

cyclic dependencies

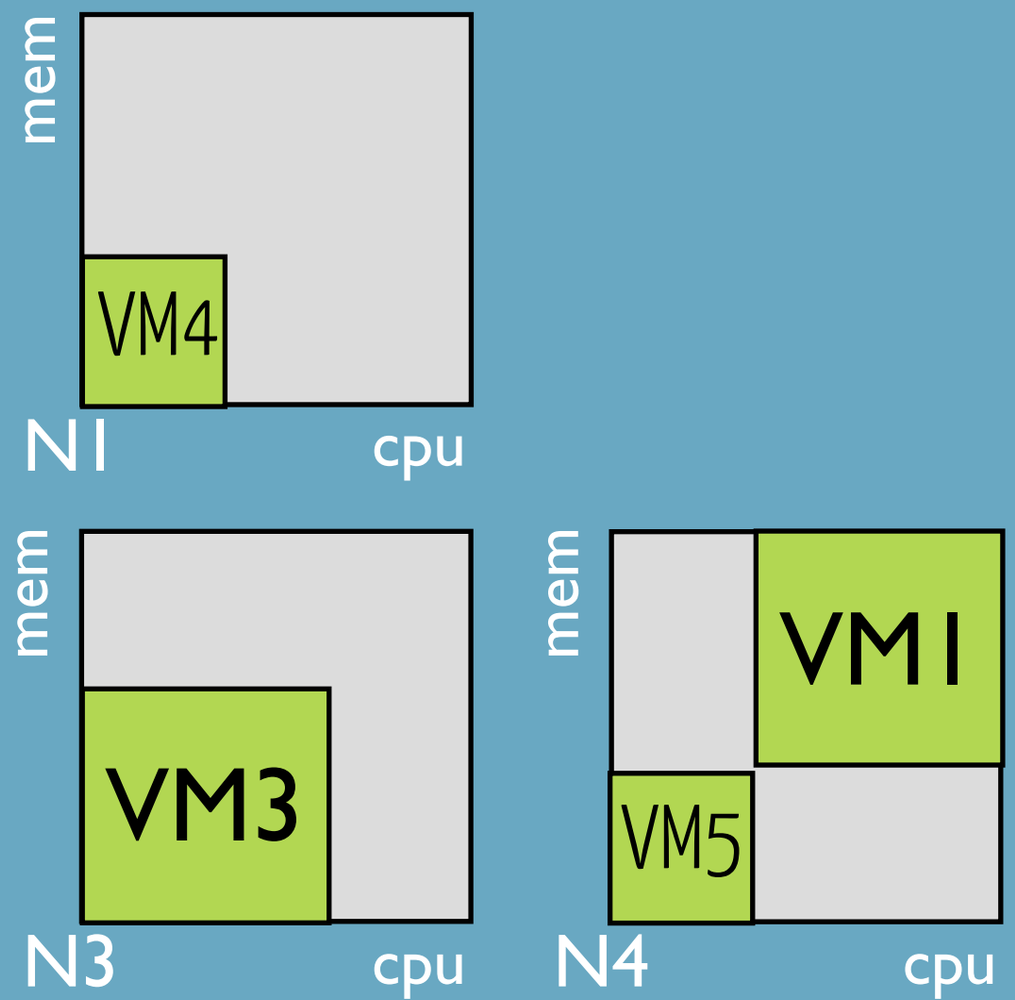


a pivot to break the cycle

fix or prevent the situation ?

dynamic schedulers

cyclic dependencies



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dynamic schedulers

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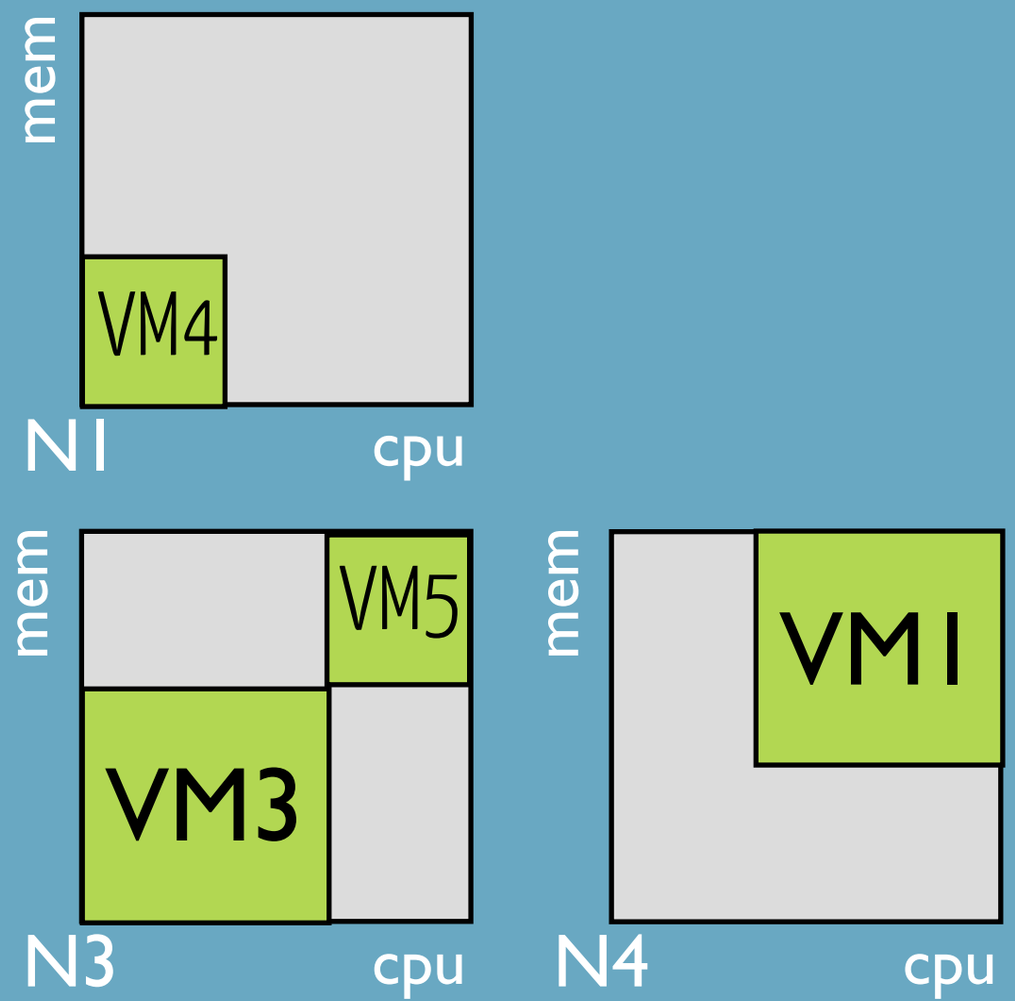

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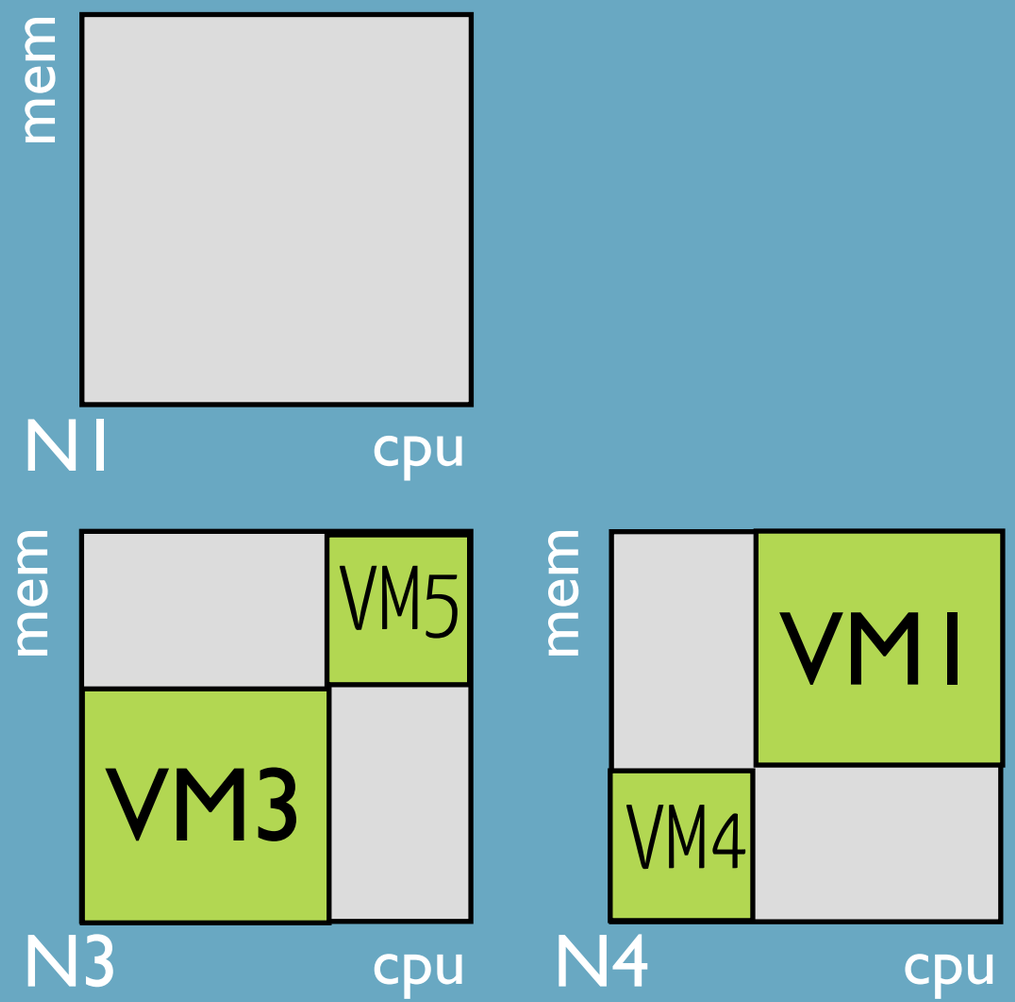

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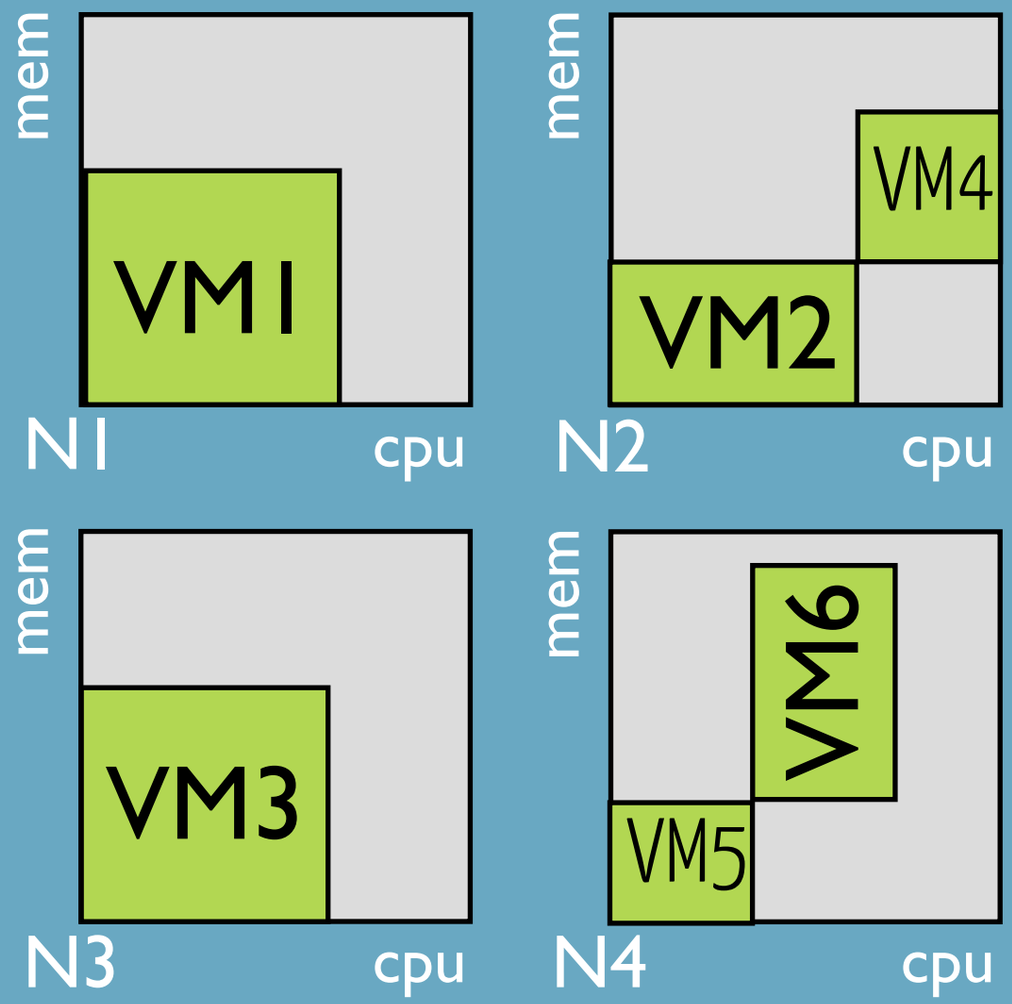
dynamic schedulers

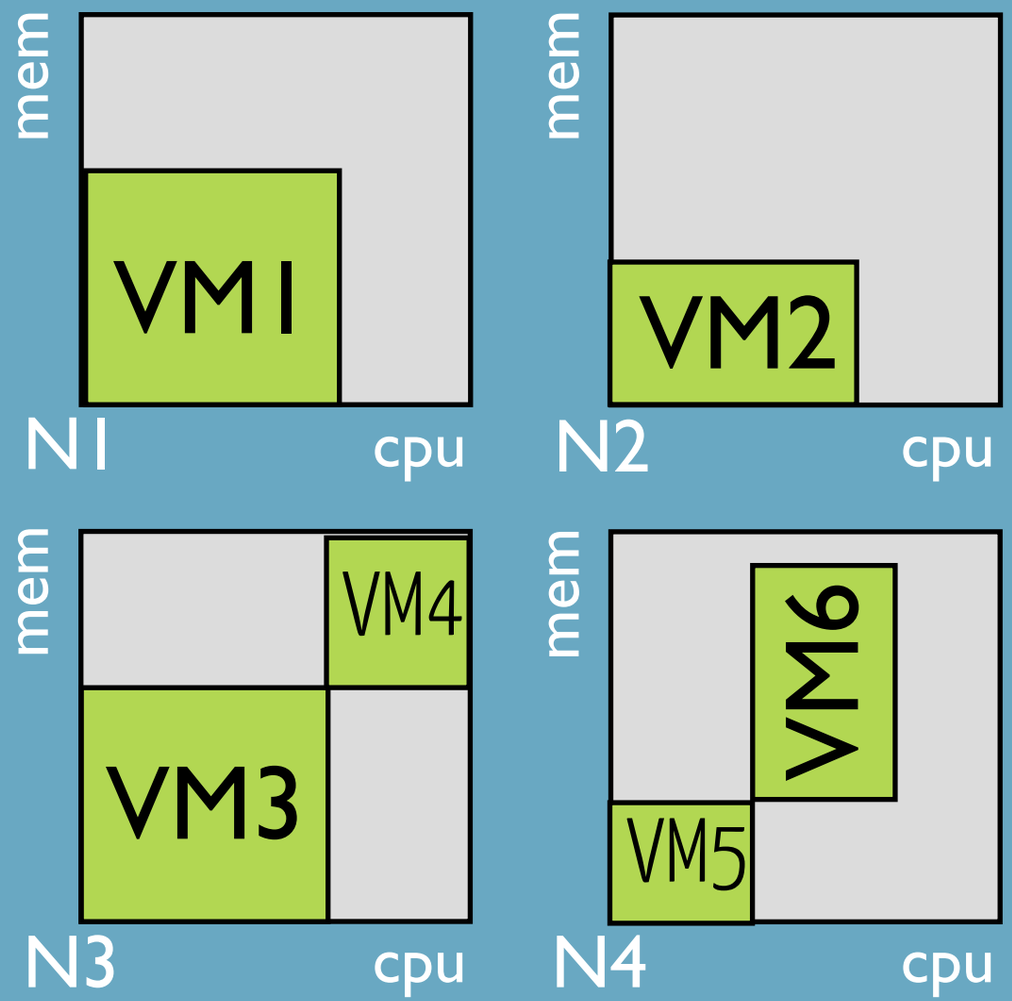
quality at a price



min(#onlineNodes) = 3

dynamic schedulers

quality at a price



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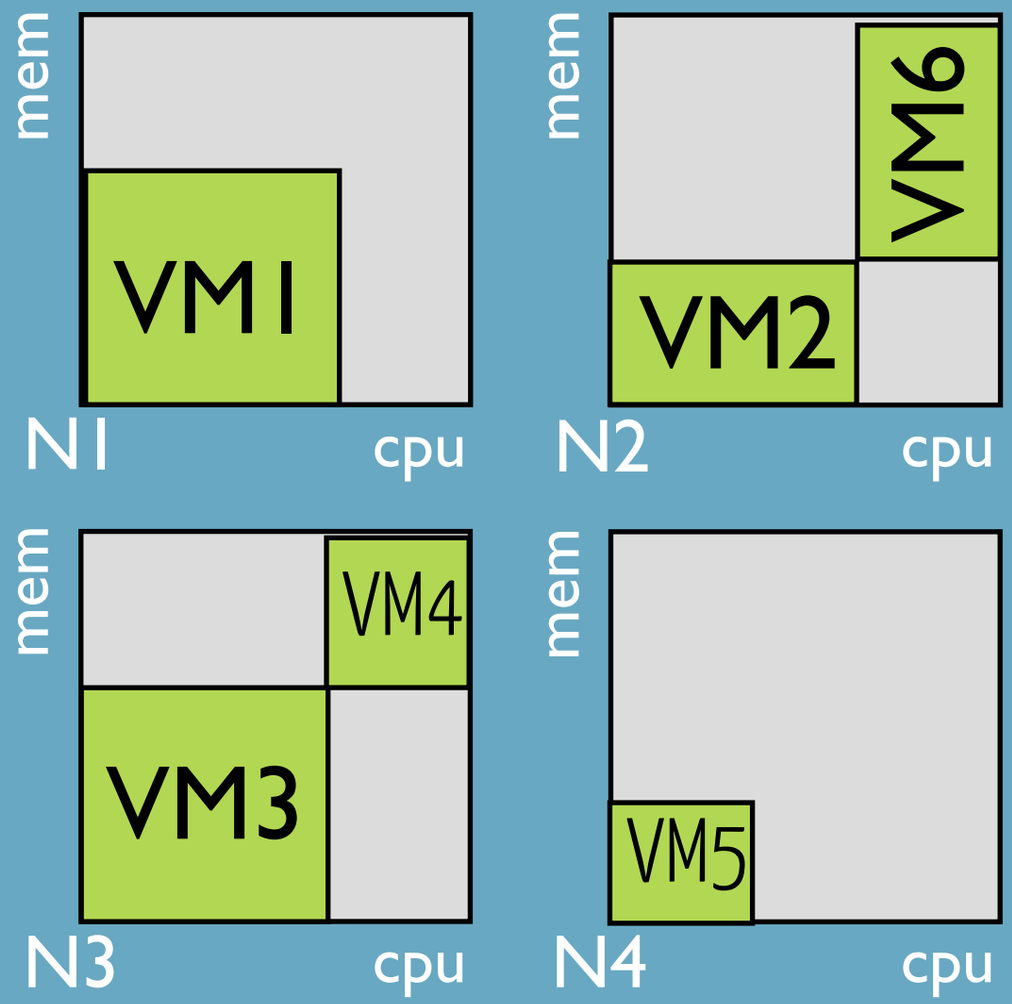
dynamic schedulers

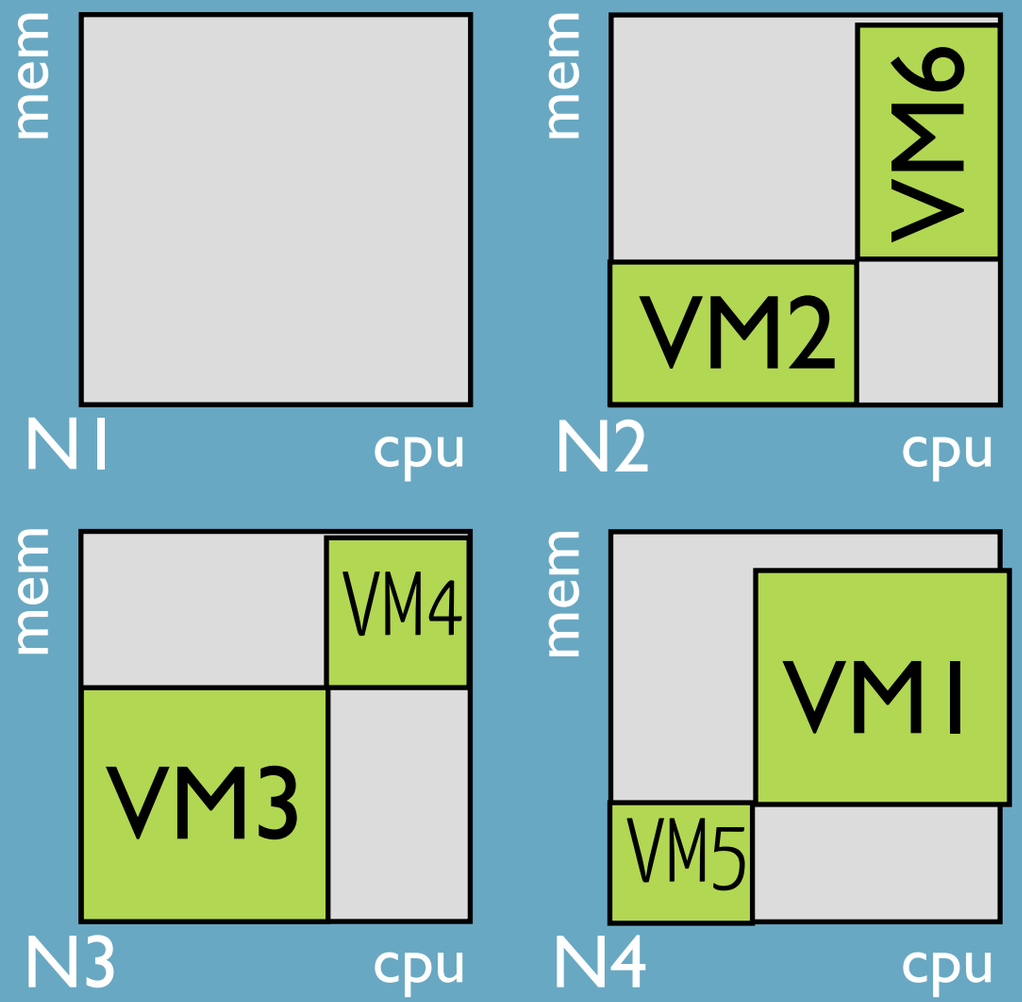
quality at a price



min(#onlineNodes) = 3

dynamic schedulers

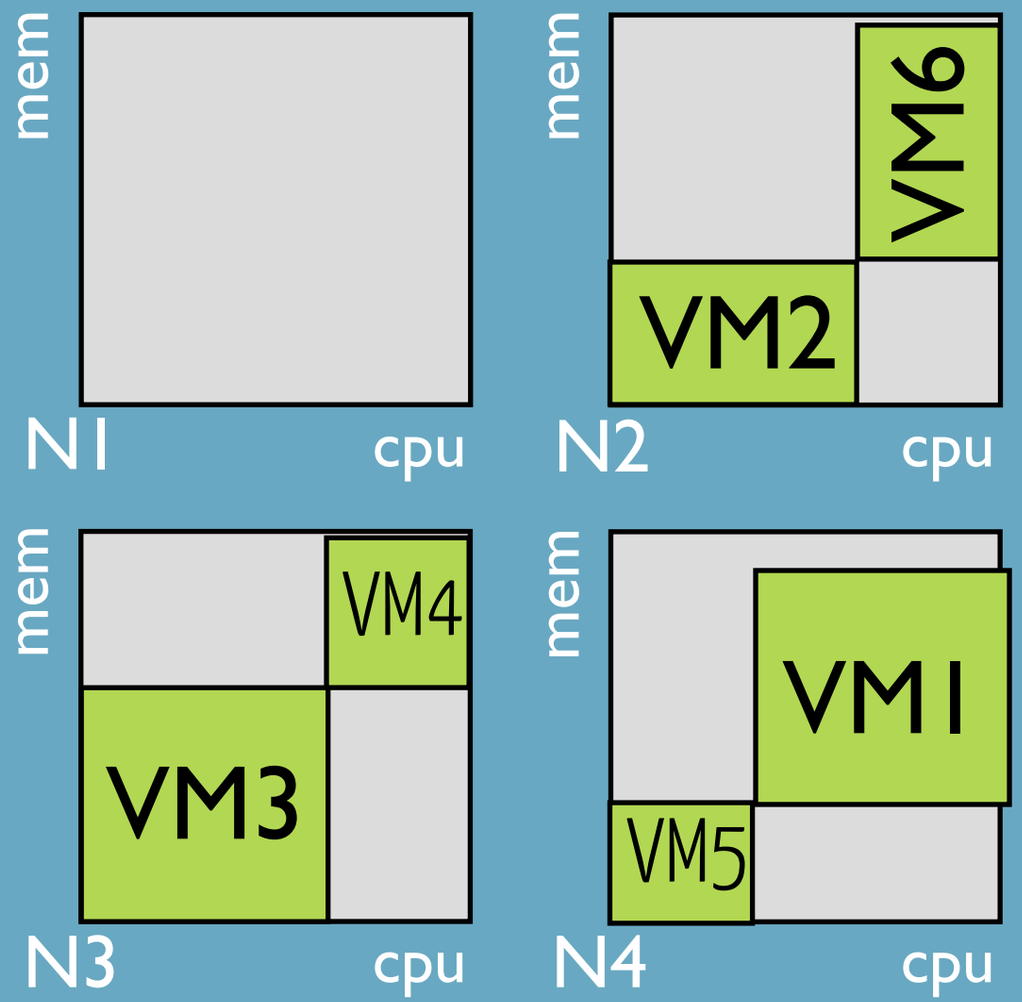
quality at a price



$$min(\#onlineNodes) = 3$$

dynamic schedulers

quality at a price

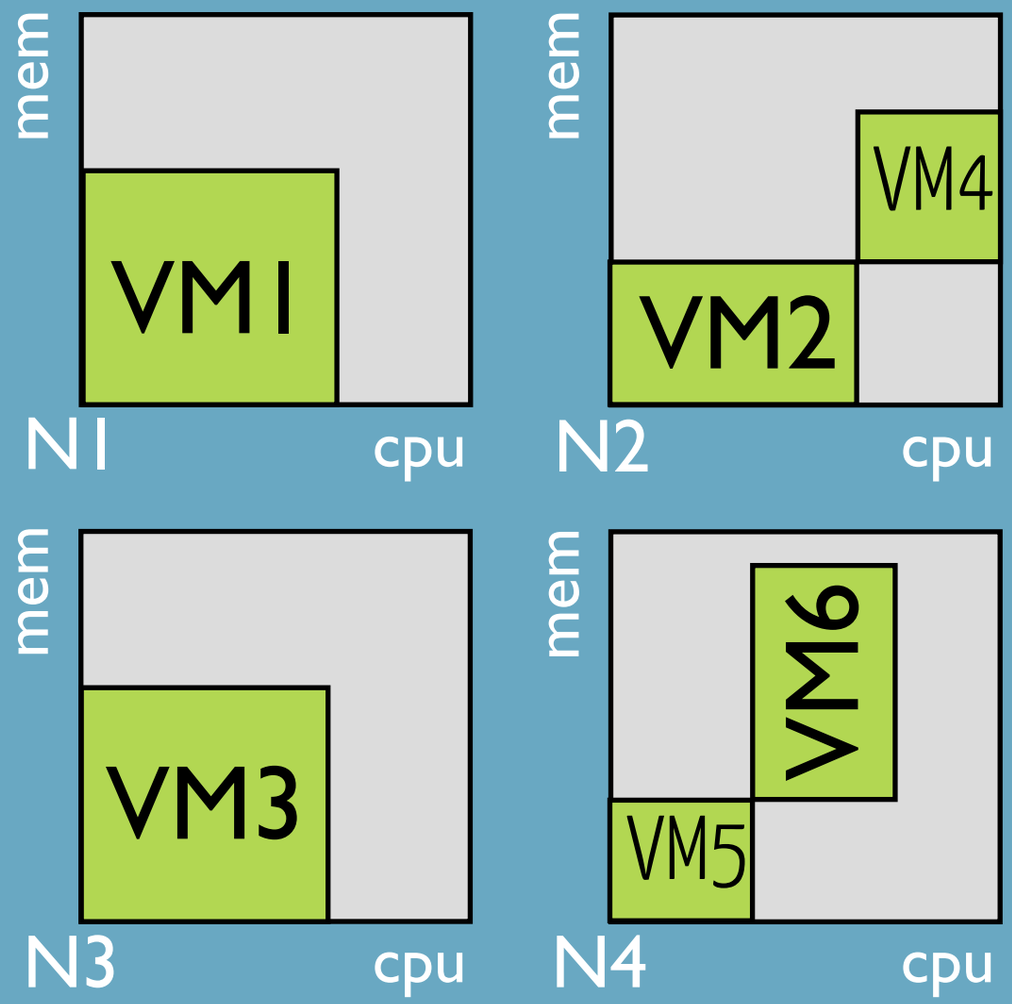


sol #1: 1m,1m,2m

min(#onlineNodes) = 3

dynamic schedulers

quality at a price



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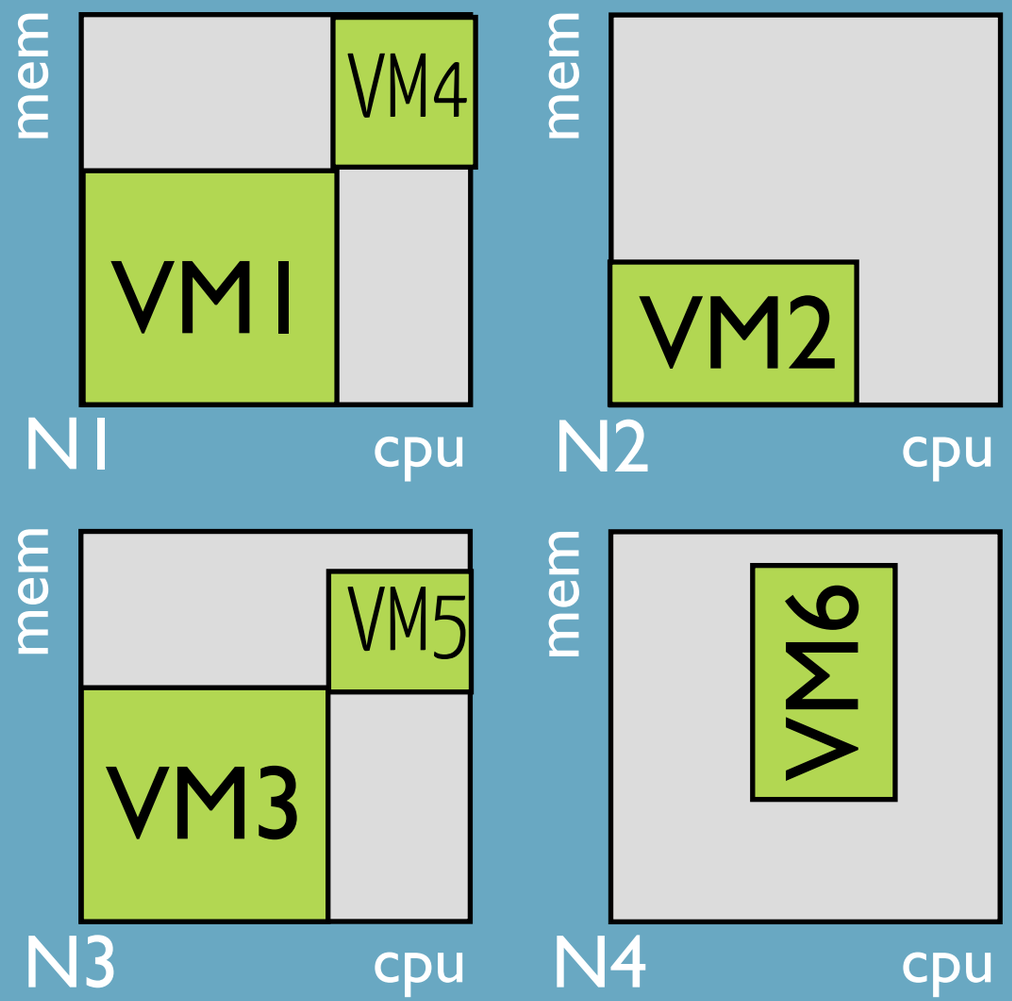
dynamic schedulers

quality at a price



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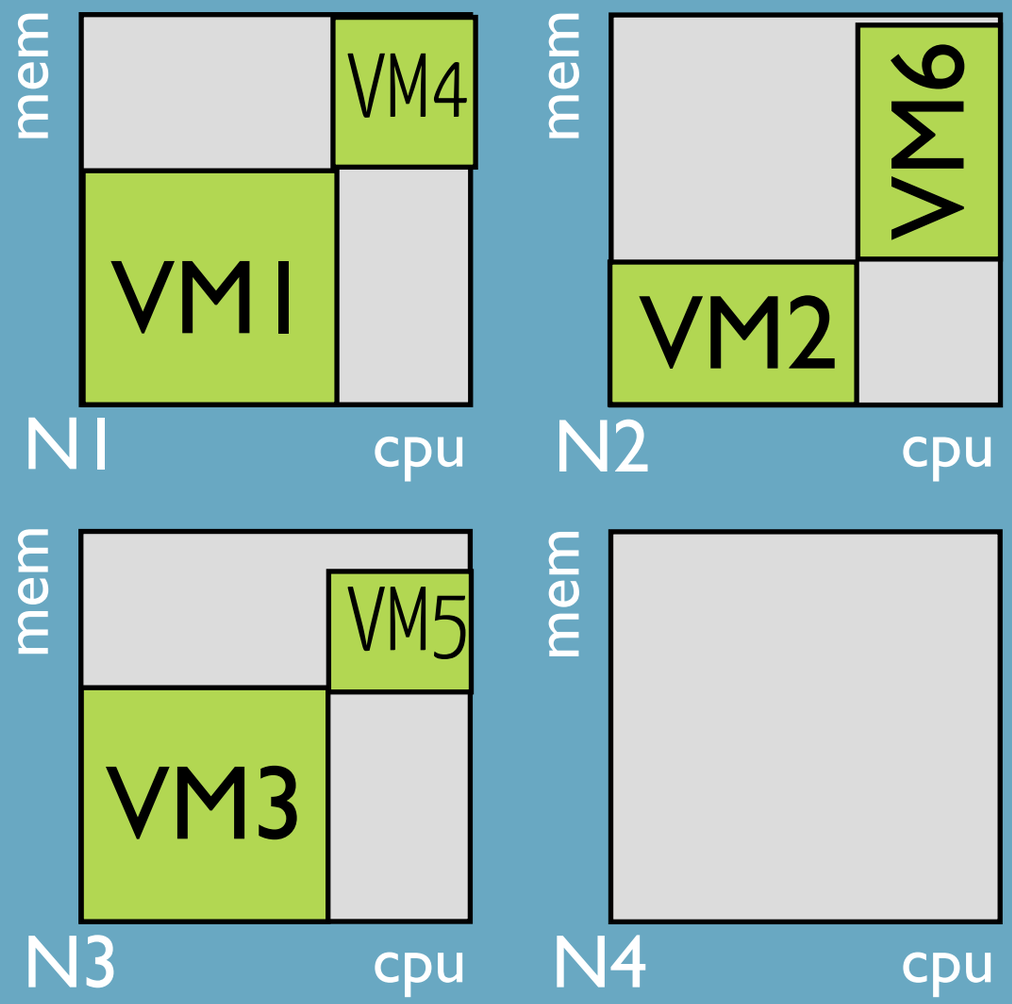

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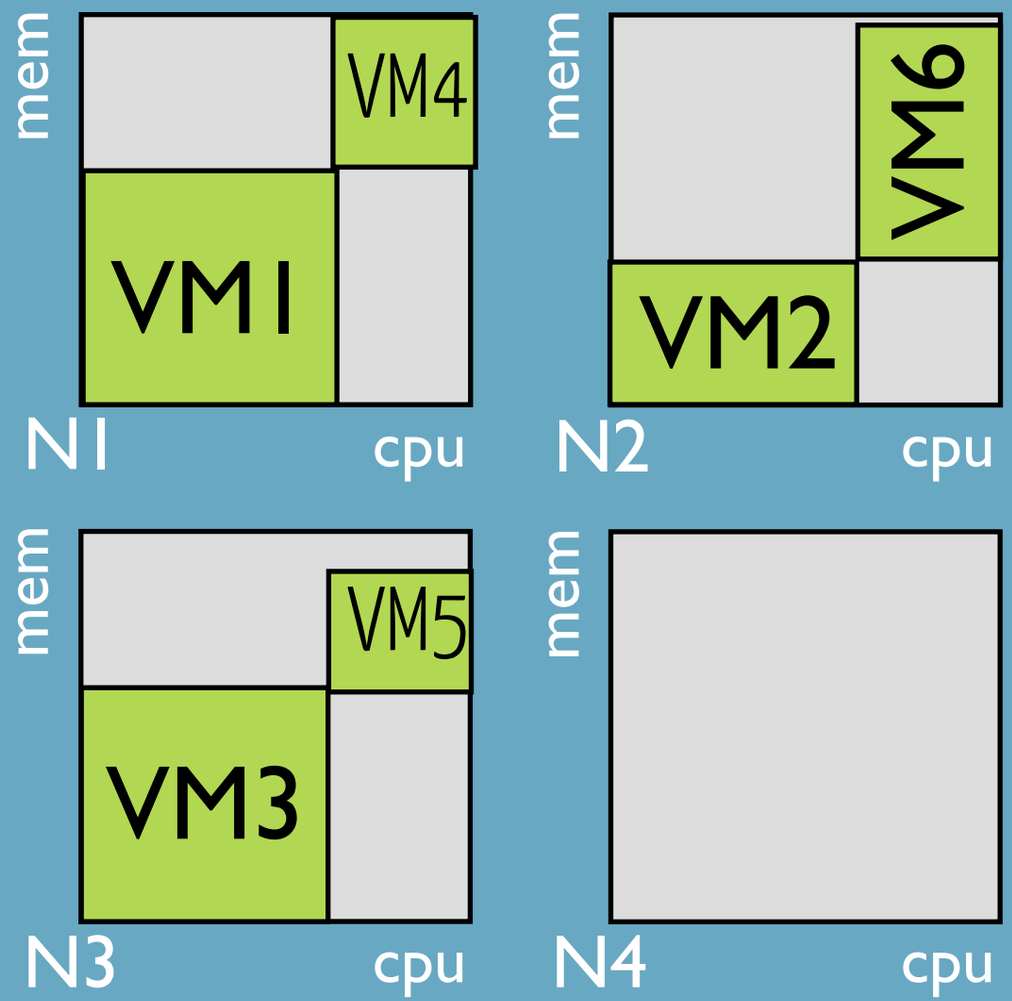
dynamic schedulers

quality at a price



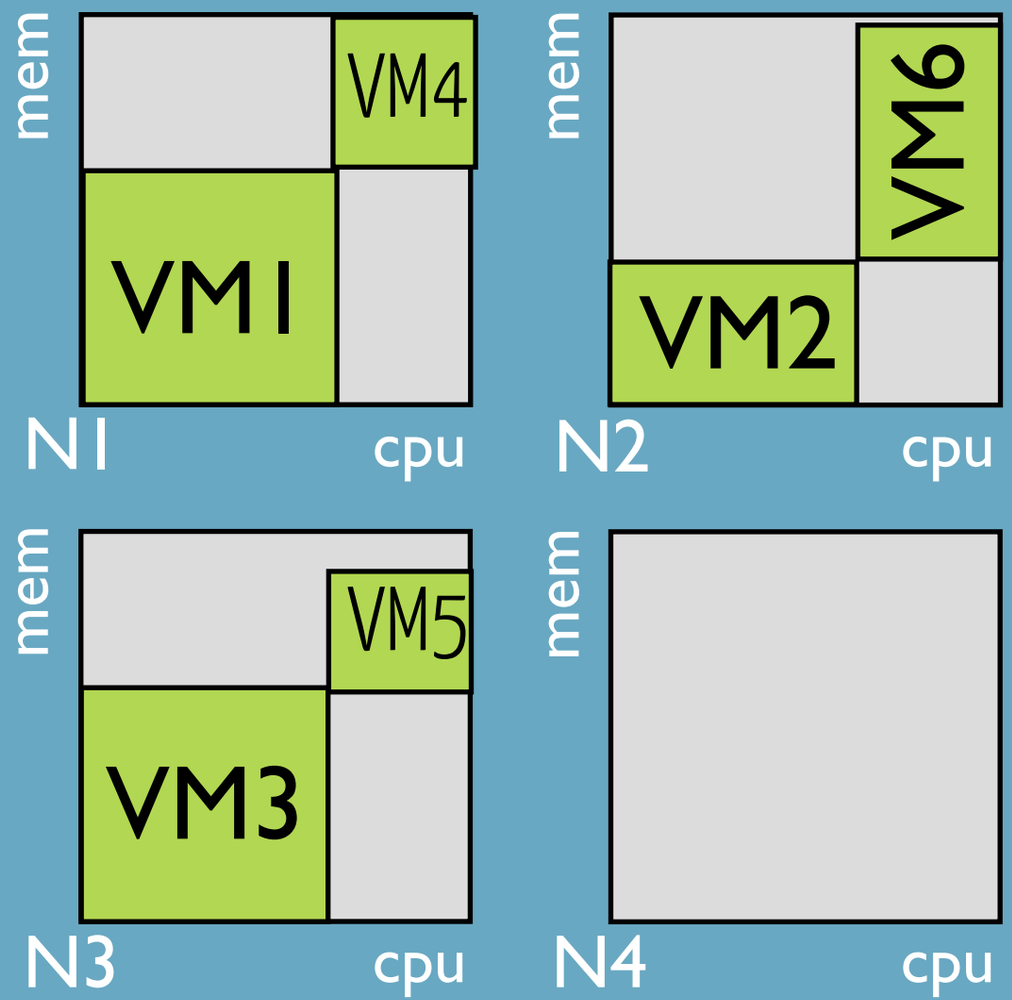
sol #1: 1m,1m,2m

sol #2: 1m,1m
1m

min(#onlineNodes) = 3

dynamic schedulers

quality at a price



min(#onlineNodes) = 3

sol #1: 1m,1m,2m

sol #2: 1m,1m
1m

lower MTTR
(faster)

dynamic schedulers

quality at a price

the objective should reflect reconfiguration costs

min(MTTR), min(#migrations),…

dynamic schedulers

pros

continuous optimisation
through reconfiguration

dynamic schedulers

cons

harder to model
harder to scale
technically expensive
costly reconfiguration

dynamic scheduling for the win ?

in theory yes but that's theory

benefits depends on
- the workload
- the objective/ SLAs
- the infrastructure

dynamic scheduling is rare
in public or large clouds

scheduling models

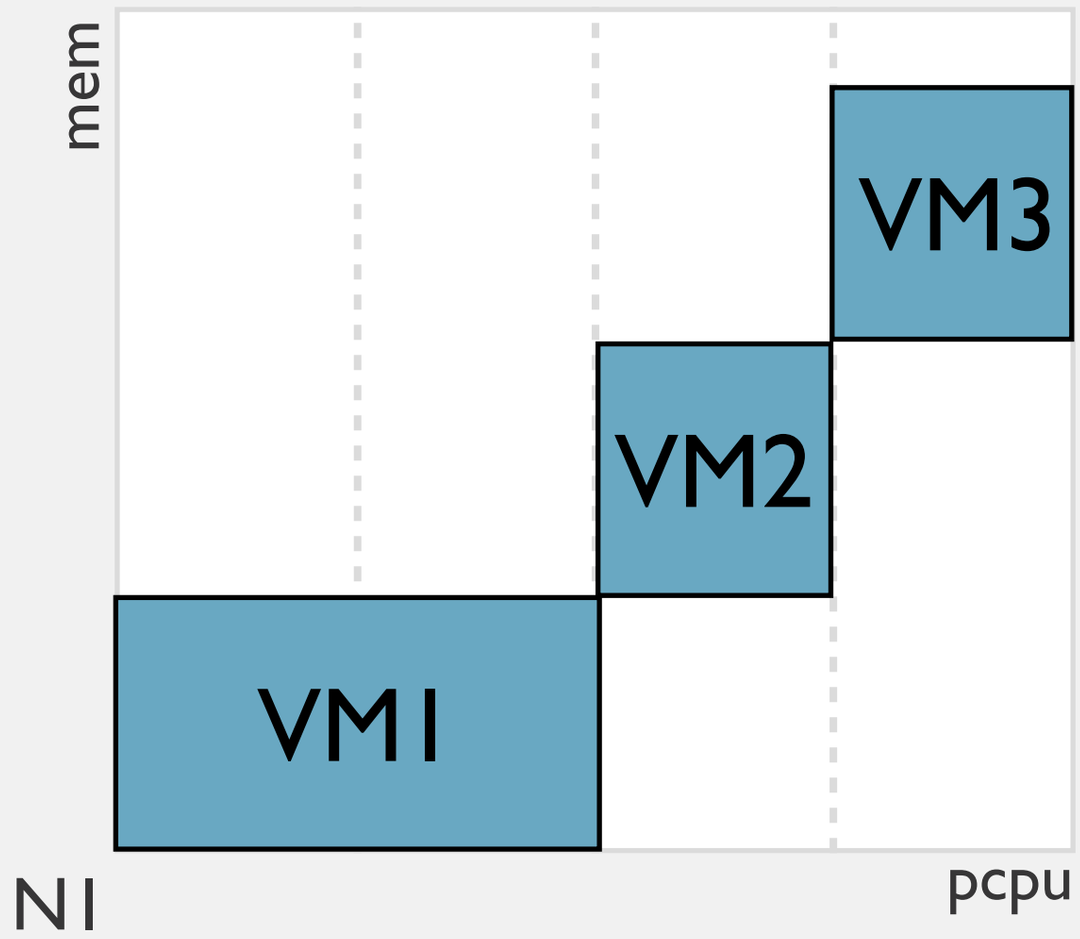
static
dynamic

resource allocation

static
dynamic

schedulers

static resource allocation



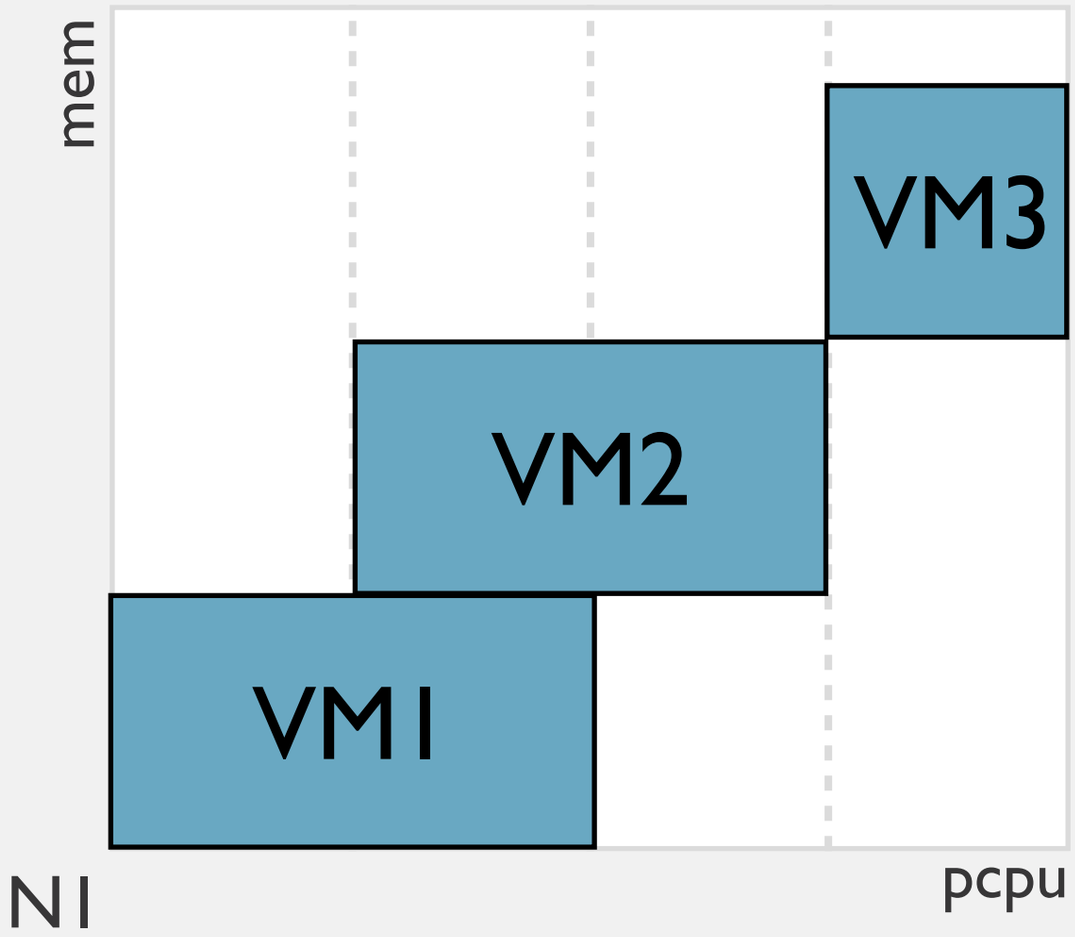
cpu, ram, i/o, bandwidth
allocated once for all

allocation != utilisation

no sharing
conservative allocation

static resource allocation

sharing (overbooking)

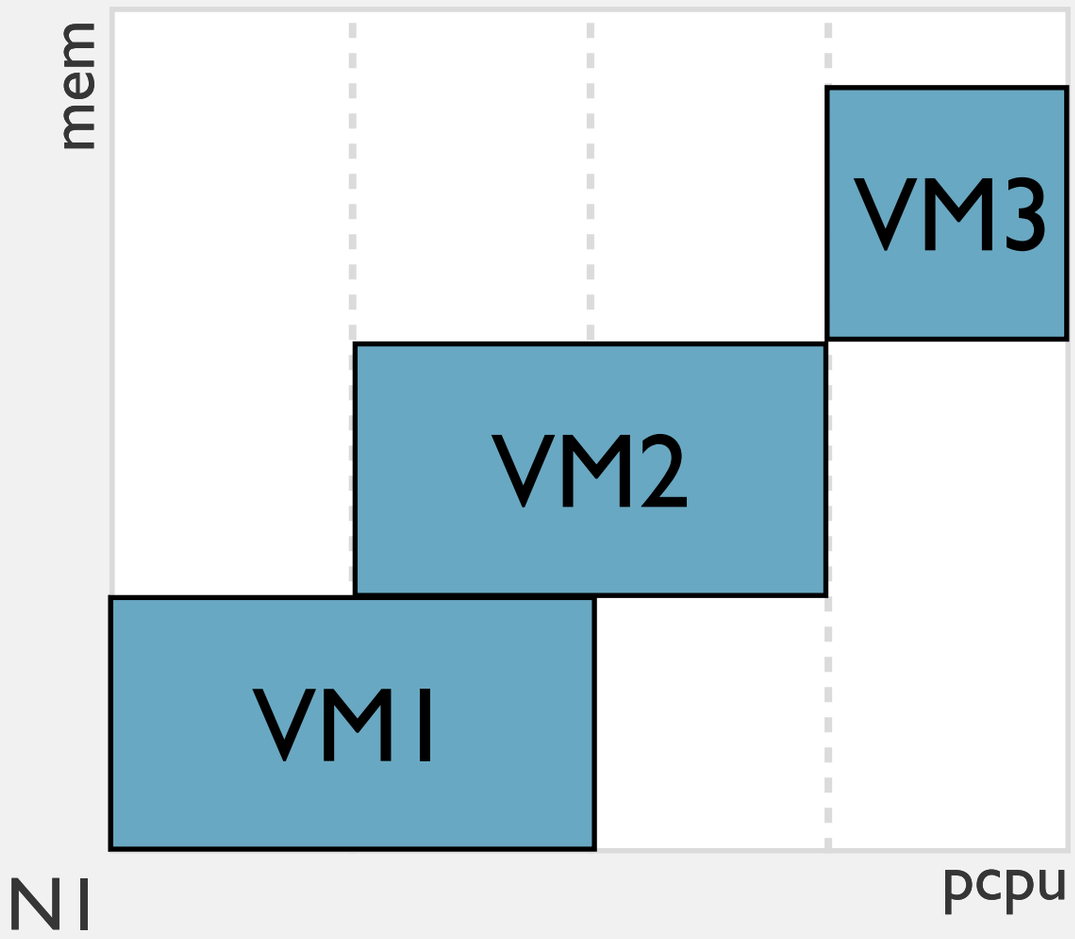


performance loss
with concurrent accesses

acceptable if stated
in the SLA

dynamic resource allocation

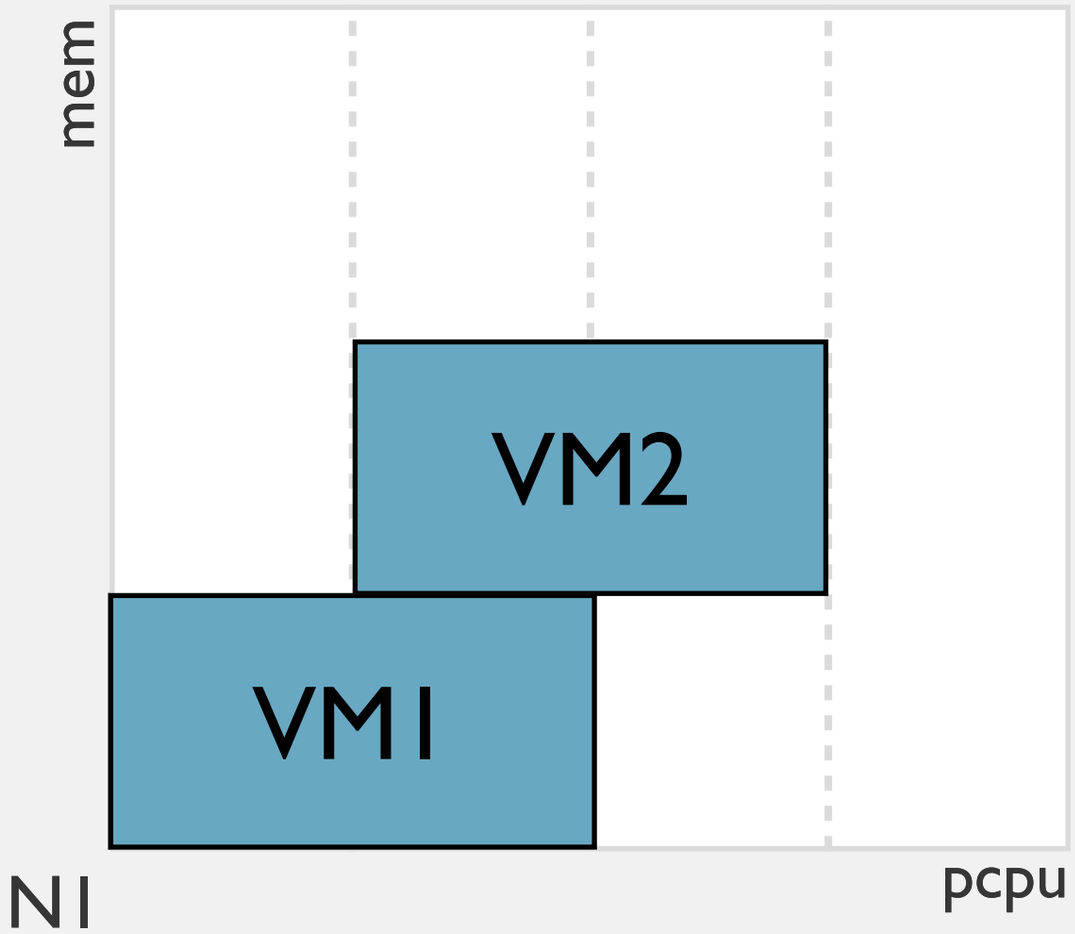
to fix violations



cpu, ram, i/o, bandwidth
allocated can be revised

dynamic resource allocation

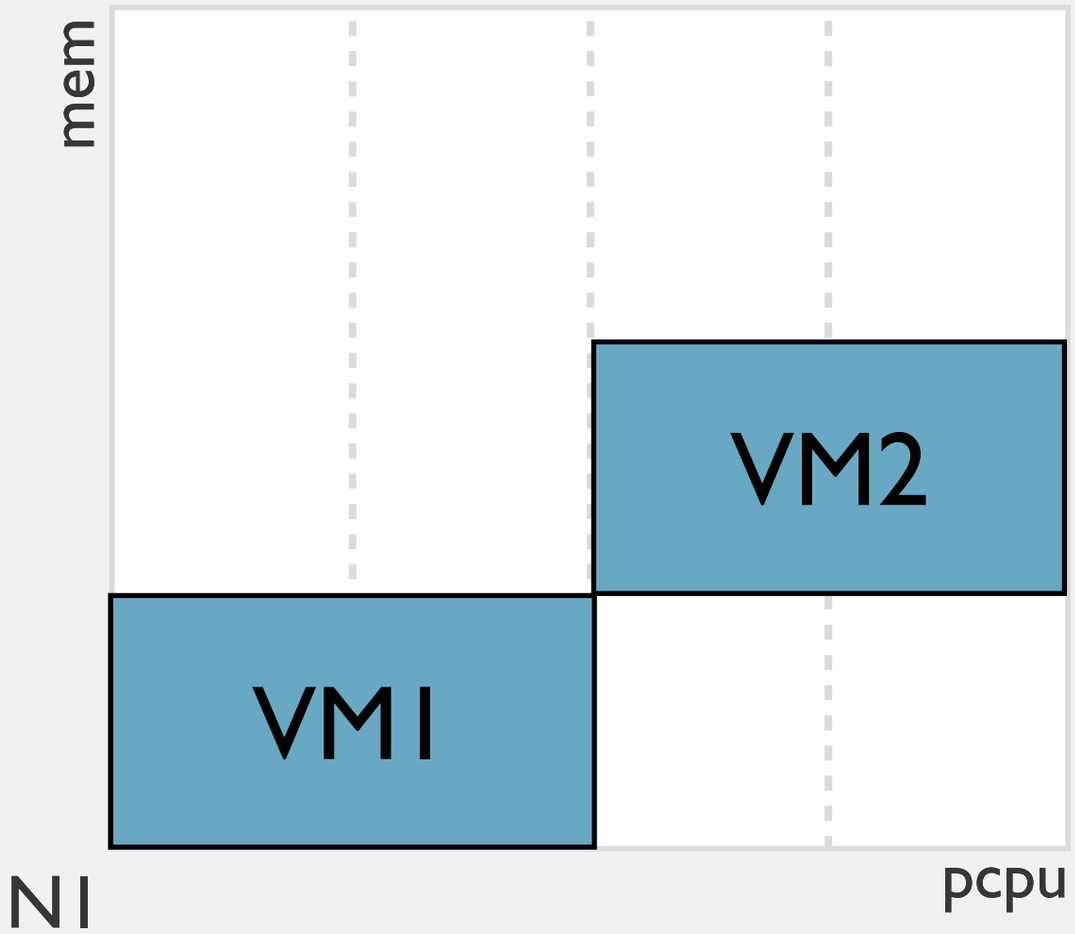
to fix violations



cpu, ram, i/o, bandwidth
allocated can be revised

dynamic resource allocation

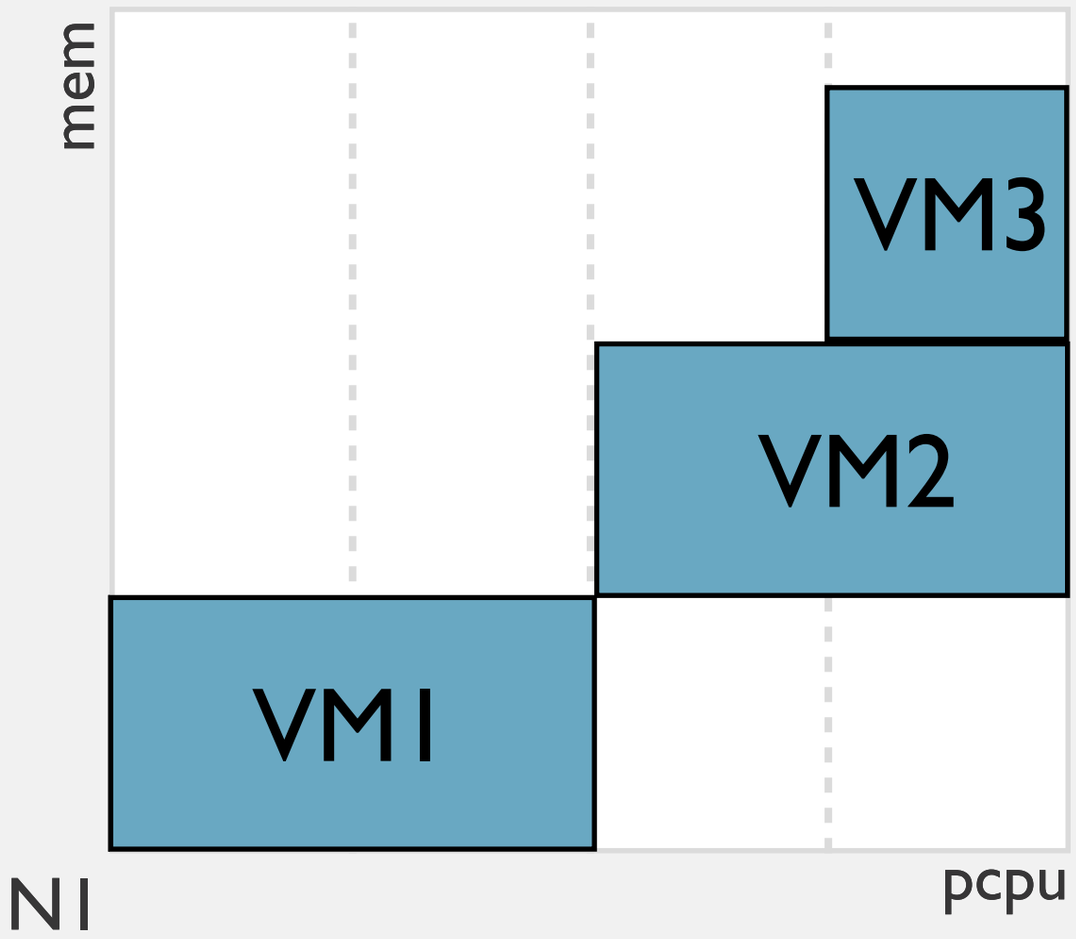
to fix violations



cpu, ram, i/o, bandwidth
allocated can be revised

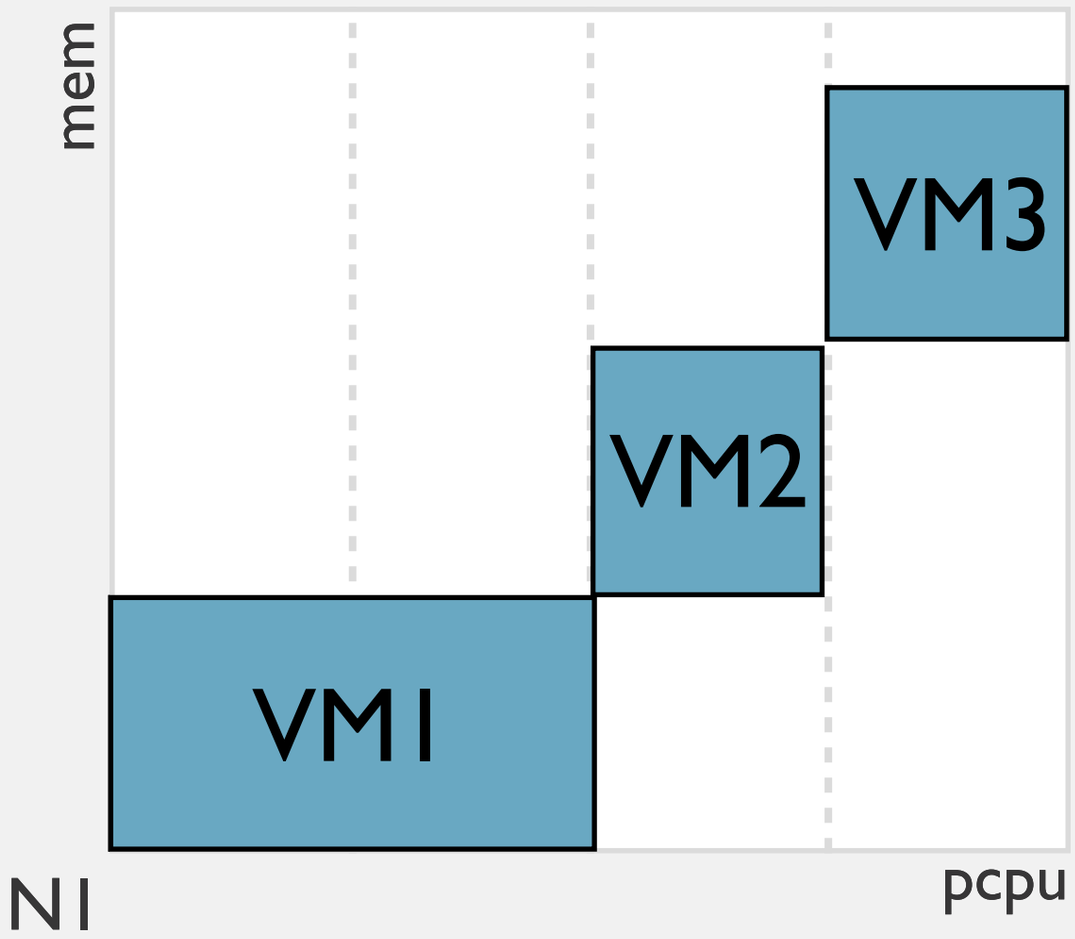
dynamic resource allocation

to support vertical elasticity



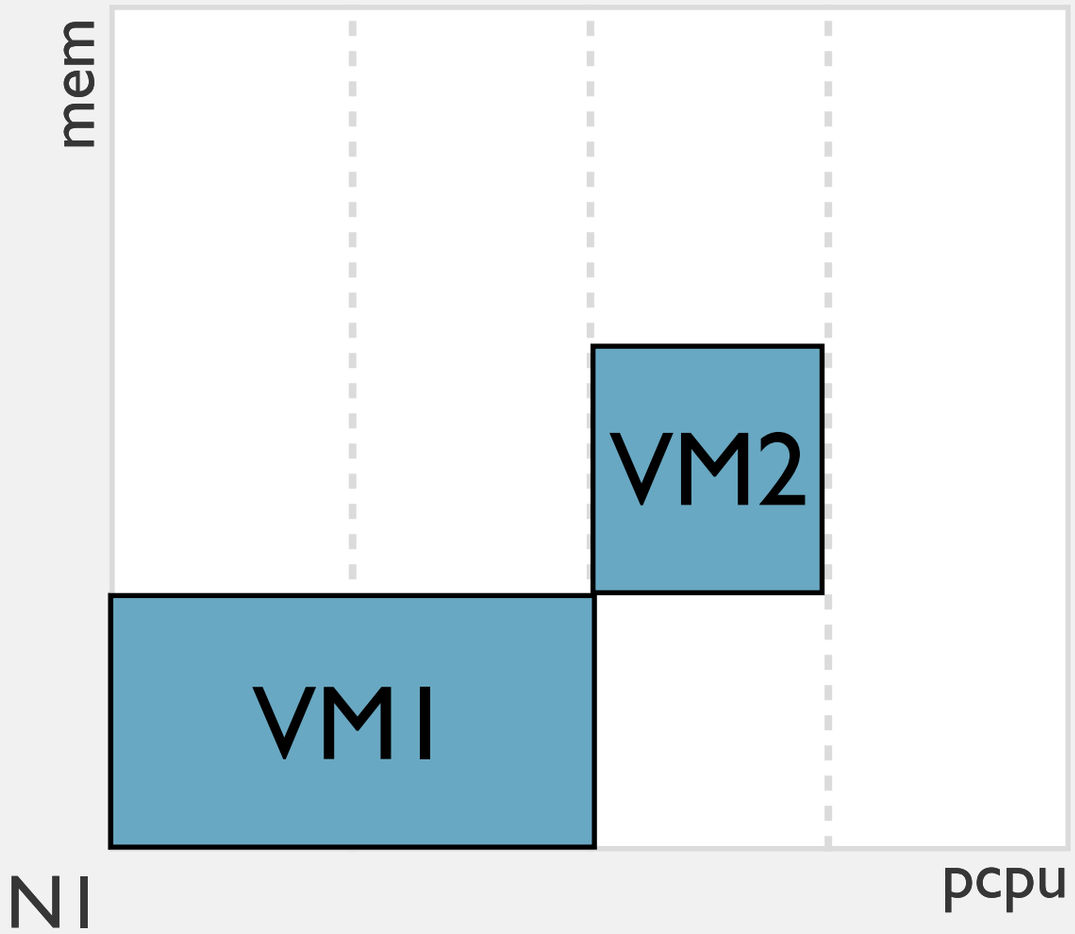
dynamic resource allocation

to support vertical elasticity



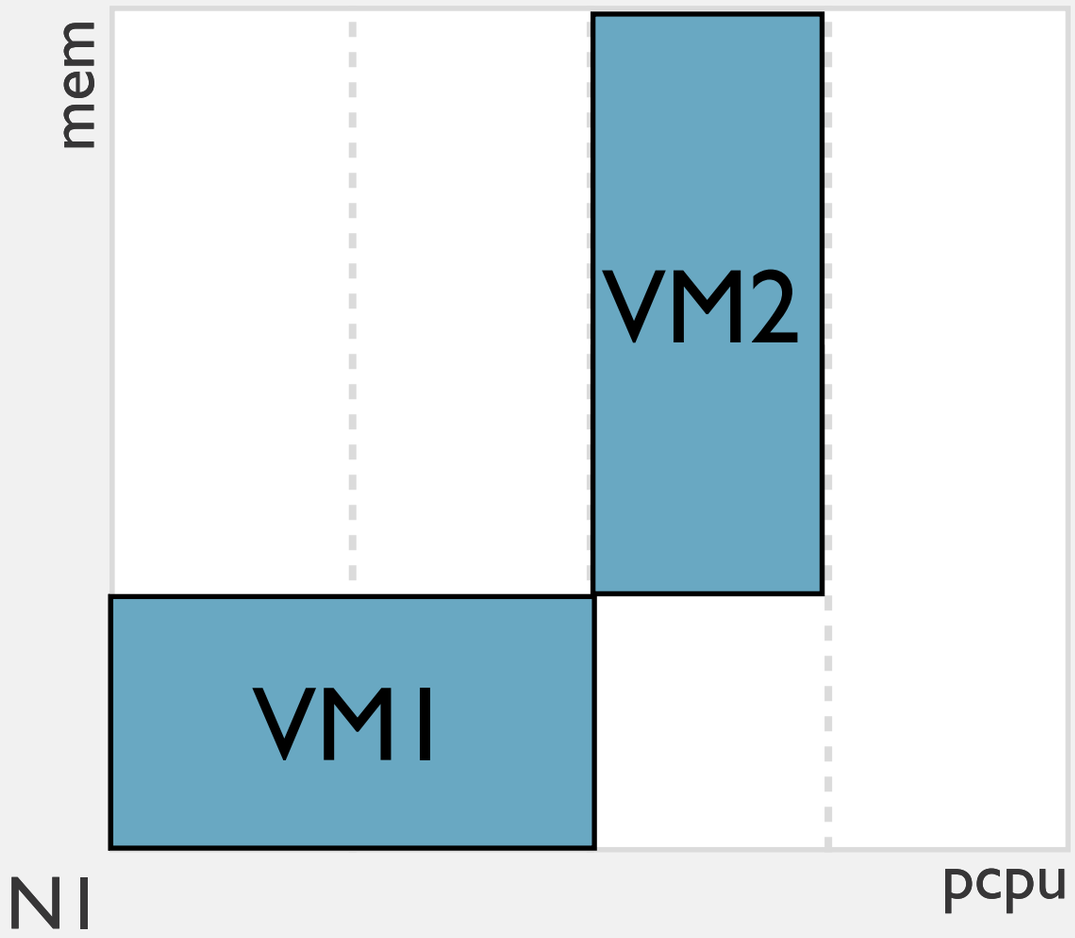
dynamic resource allocation

to support vertical elasticity



dynamic resource allocation

to support vertical elasticity



dynamic resource allocation for the win ?

common on CPU + overbooking
(inc. hosting capacity)

exceptional for memory
(huge performance loss)

benefits depends on
- the workload
- the objective/ SLAs
- the infrastructure

RECAP

The VM scheduler makes cloud benefits real

no holy grail

think about

what is costly

static scheduling for a peaceful life

dynamic scheduling to cease the day

with great power comes great responsibility

3 Coding a VM scheduler

SAFETY GLASSES

REQUIRED

VM scheduling is hard

static or dynamic scheduler allocation ?

does the workload/SLA/objective requires migration ?

maximum duration to schedule ?

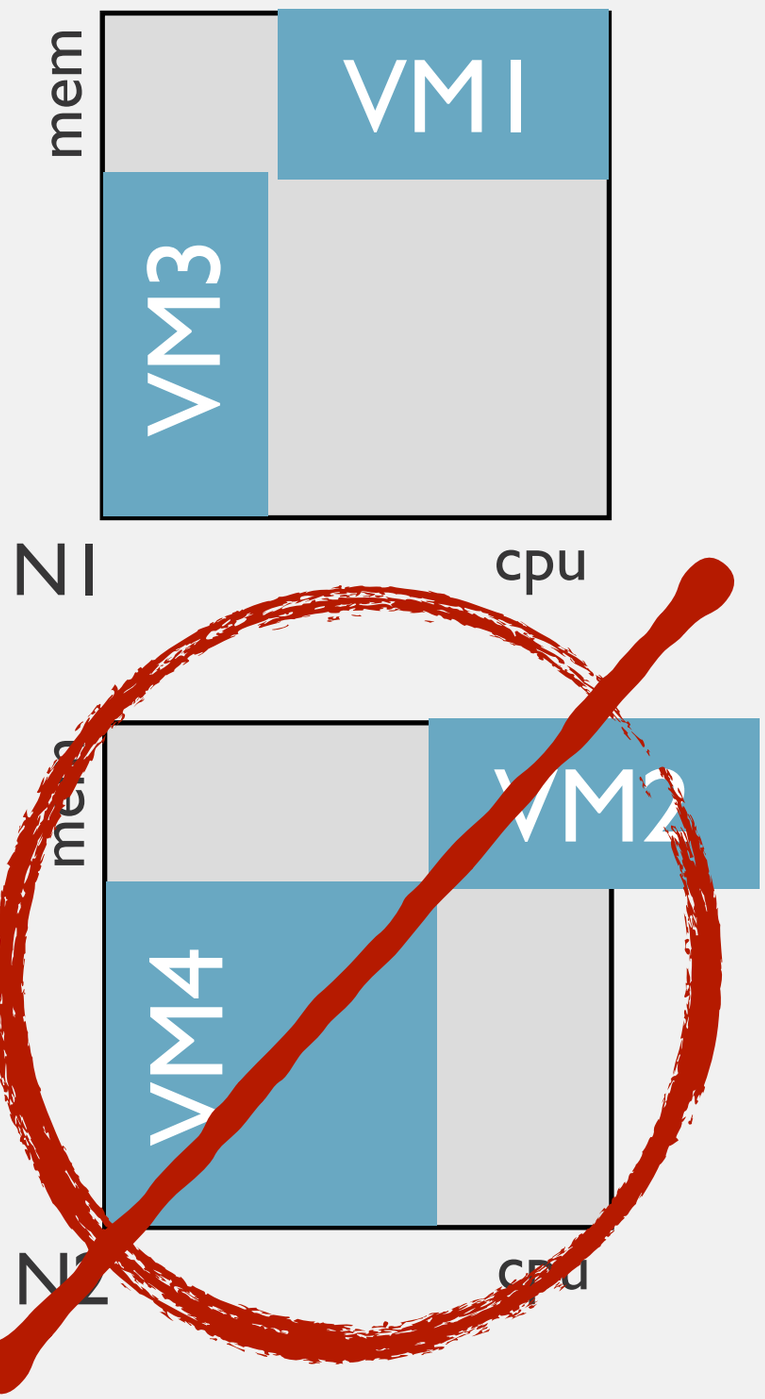
VM scheduling is NP-Hard

issues with large infrastructures
or hard problems

fast adhoc heuristics
despite corner cases

some use biased complete approaches
(linear programming, constraint programming)

vector packing problem



items with a finite volume to place inside finite bins

a generalisation of the bin packing problem

the basic to model the infra.
1 dimension = 1 resource

?

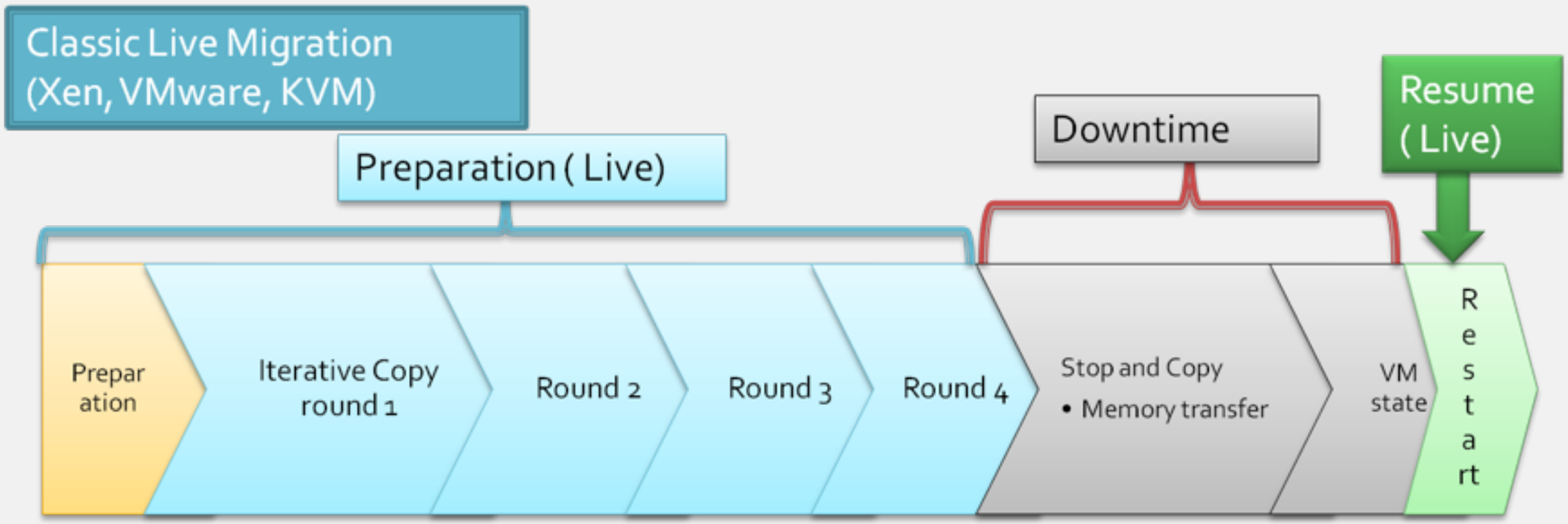
Which resource can be modeled as a packing dimension

Which resource can be modeled as a packing dimension

CPU, memory, disk IO, licences cardinality, network boundaries, ...

~~end to end network~~

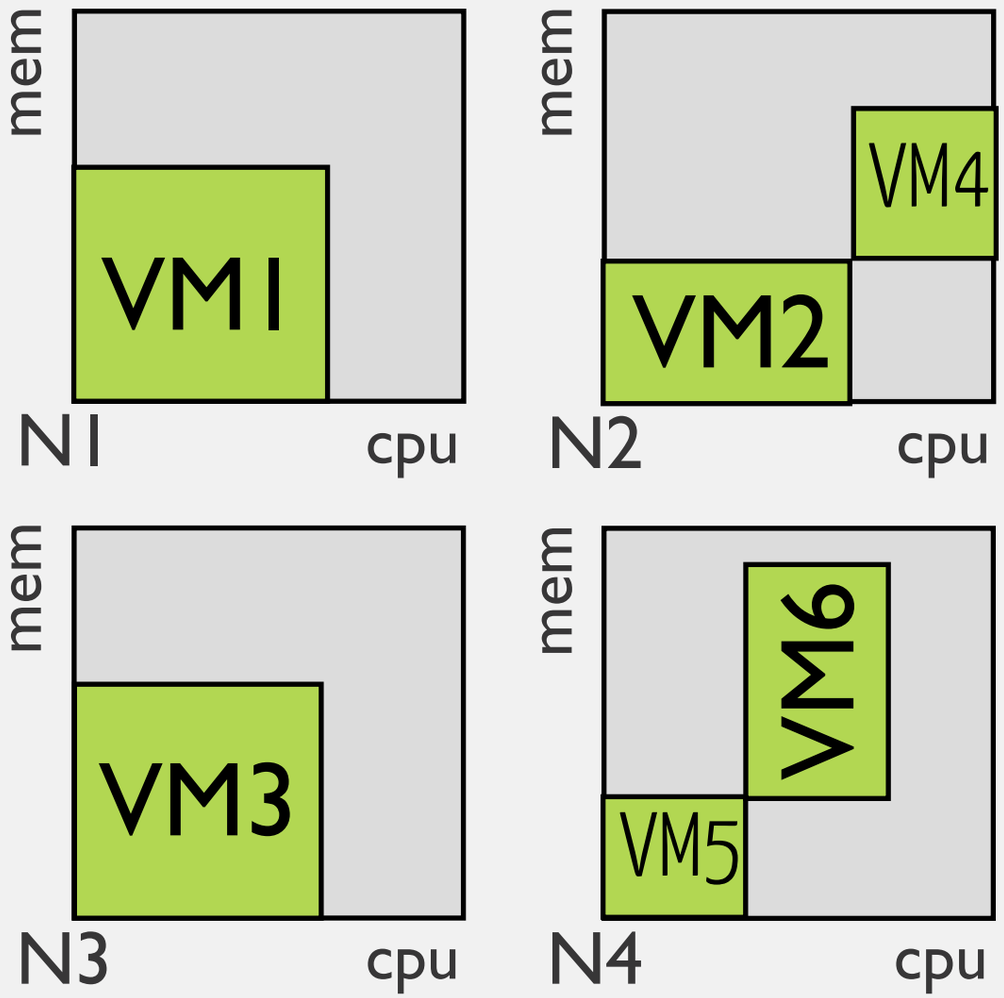
how to support migrations



temporary,
resources are used on the source and the destination nodes

how to support migrations

a simple way



n-phases vector packing

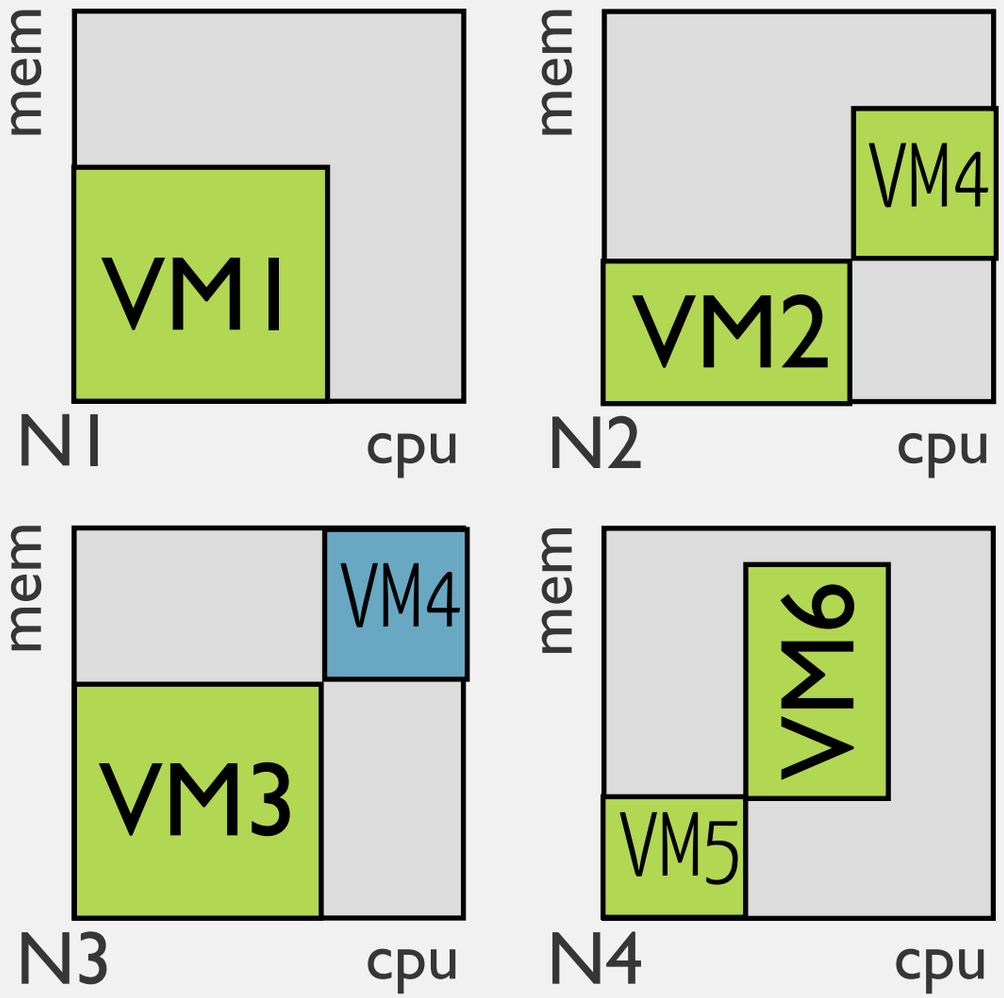
VM duplication between 2 phases
to simulate the migration

easy to implement

hard to manipulate to
compute long term previsions

how to support migrations

a simple way



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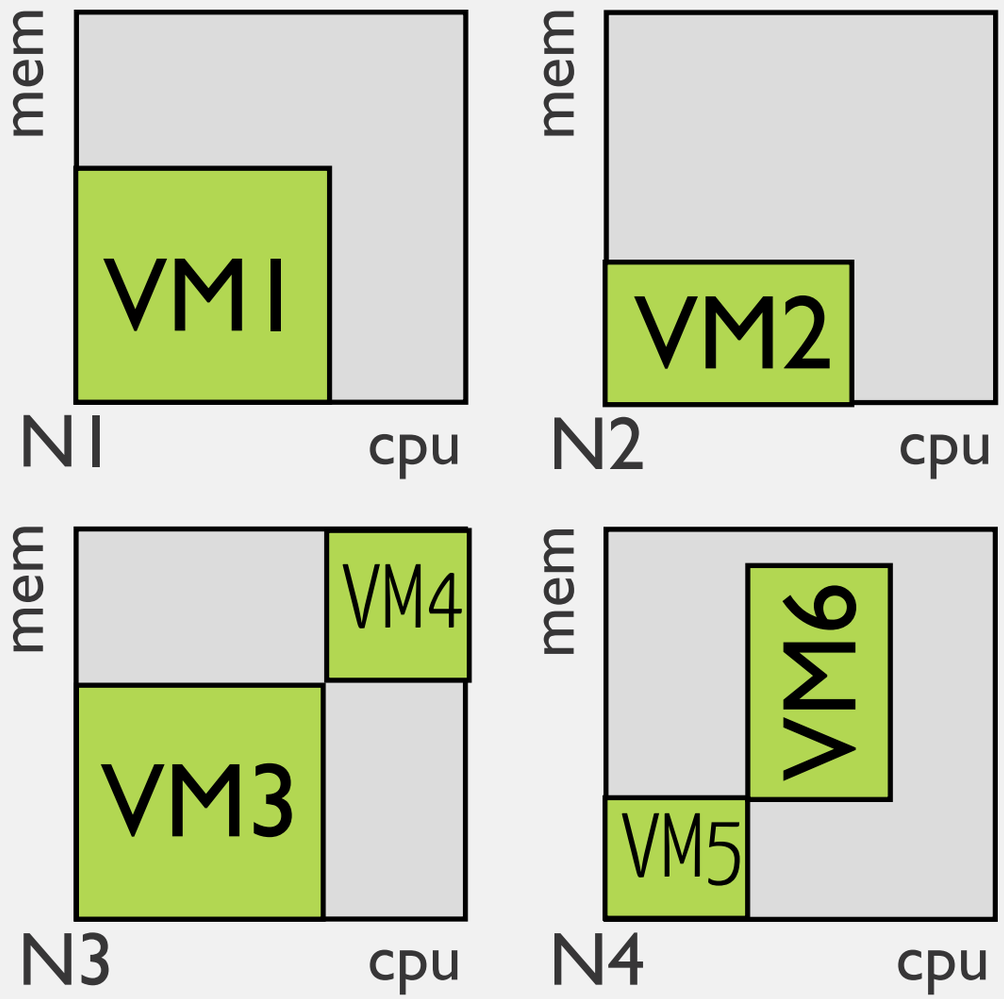

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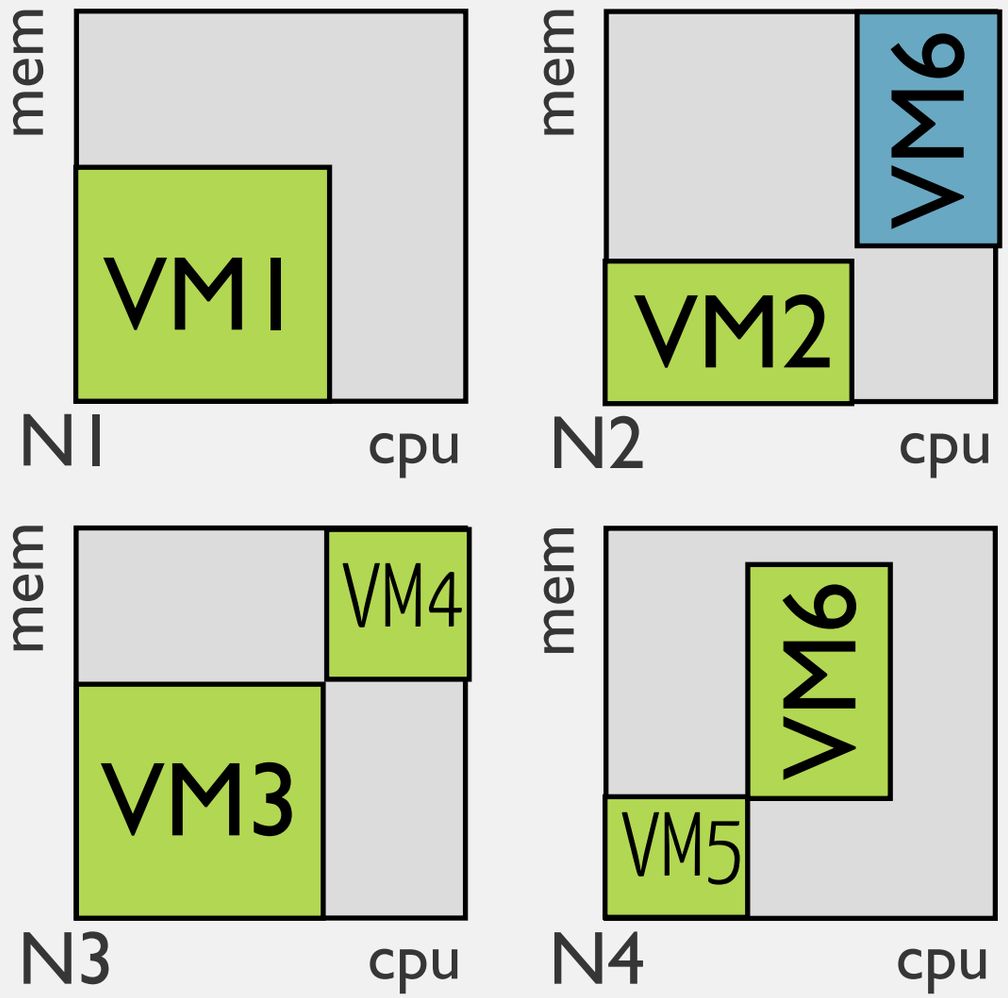

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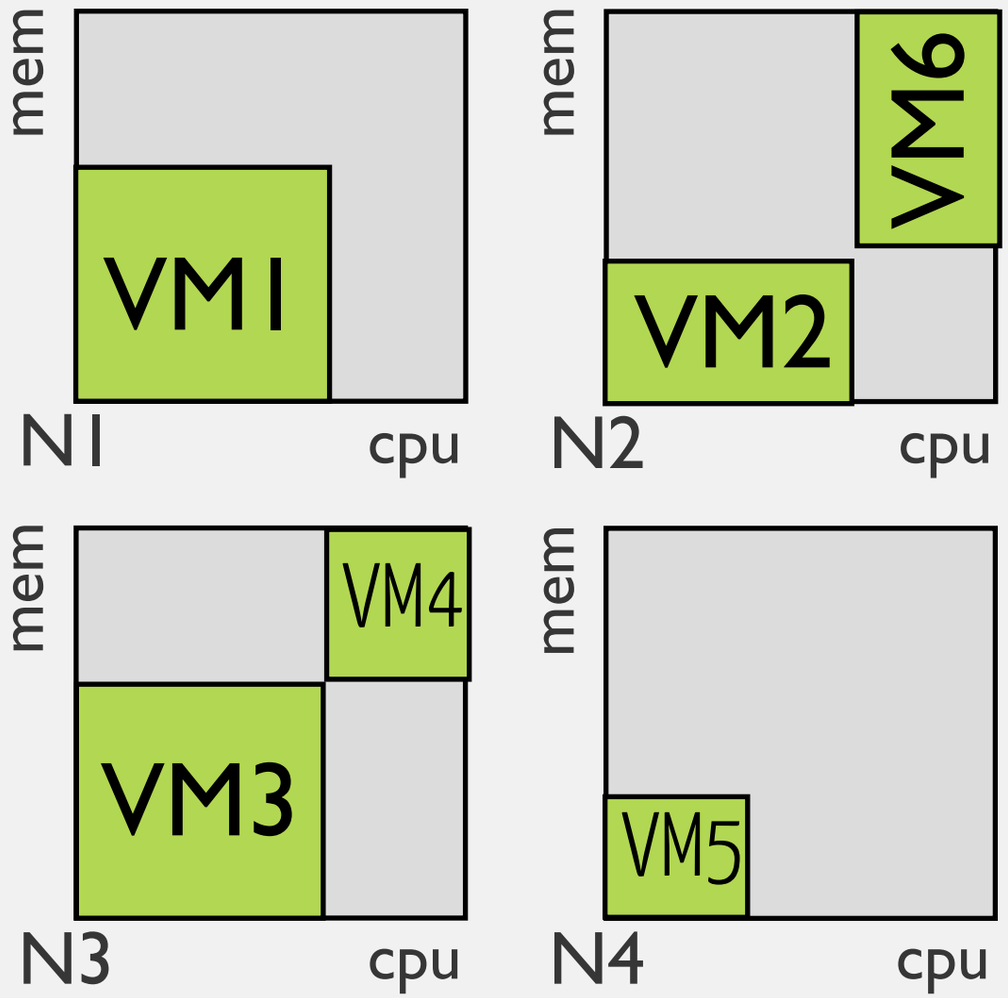

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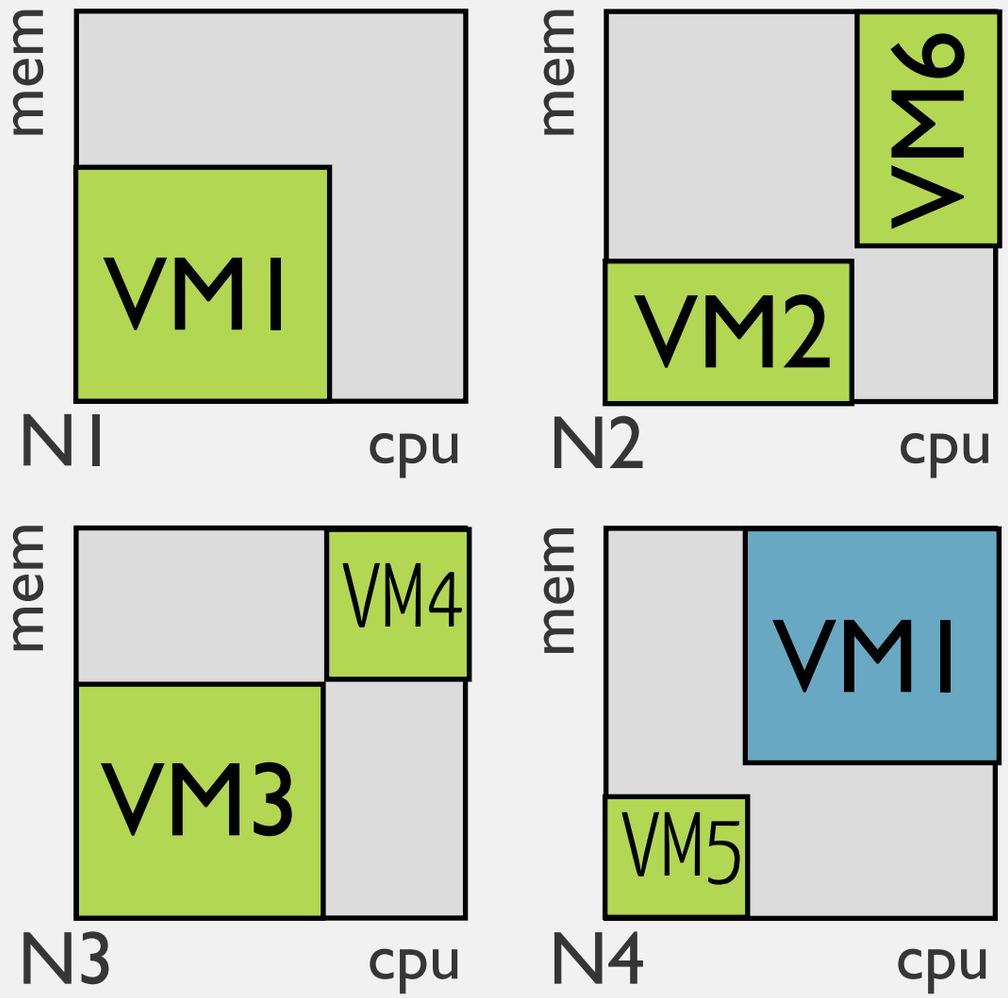
a simple way



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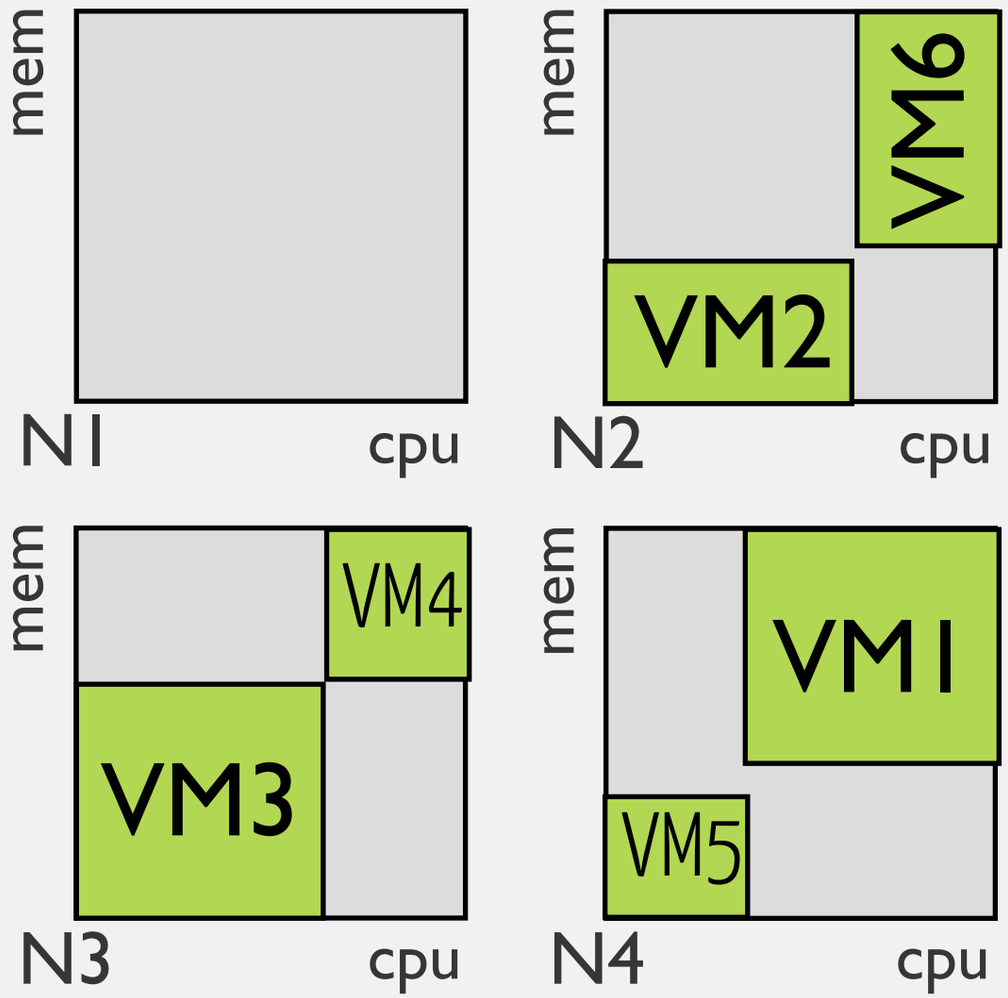


n-phases vector packing

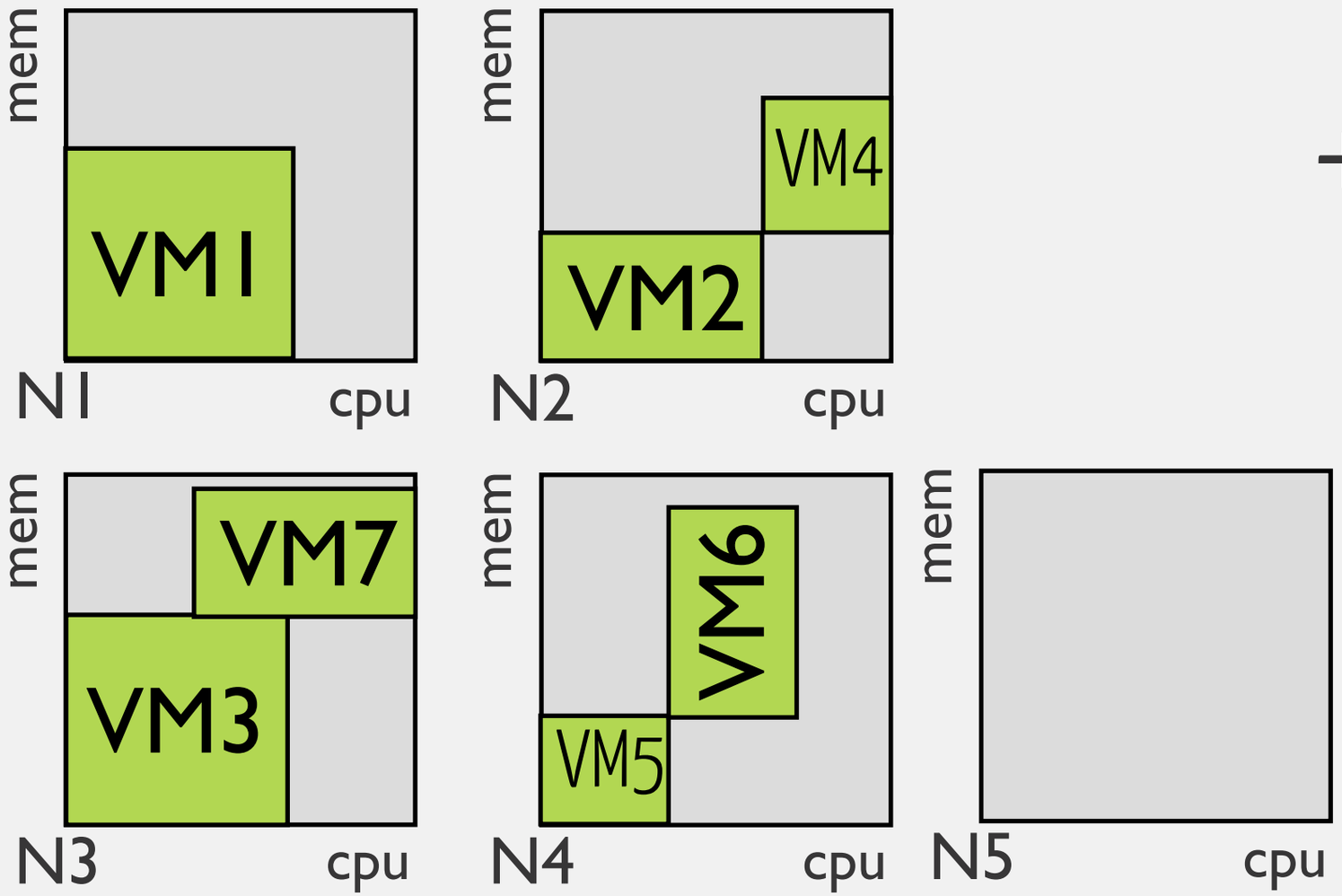
VM duplication between 2 phases
to simulate the migration

easy to implement

hard to manipulate to
compute long term previsions

how to support migrations

the alternative way



offline(N2) + no CPU sharing

1-phase

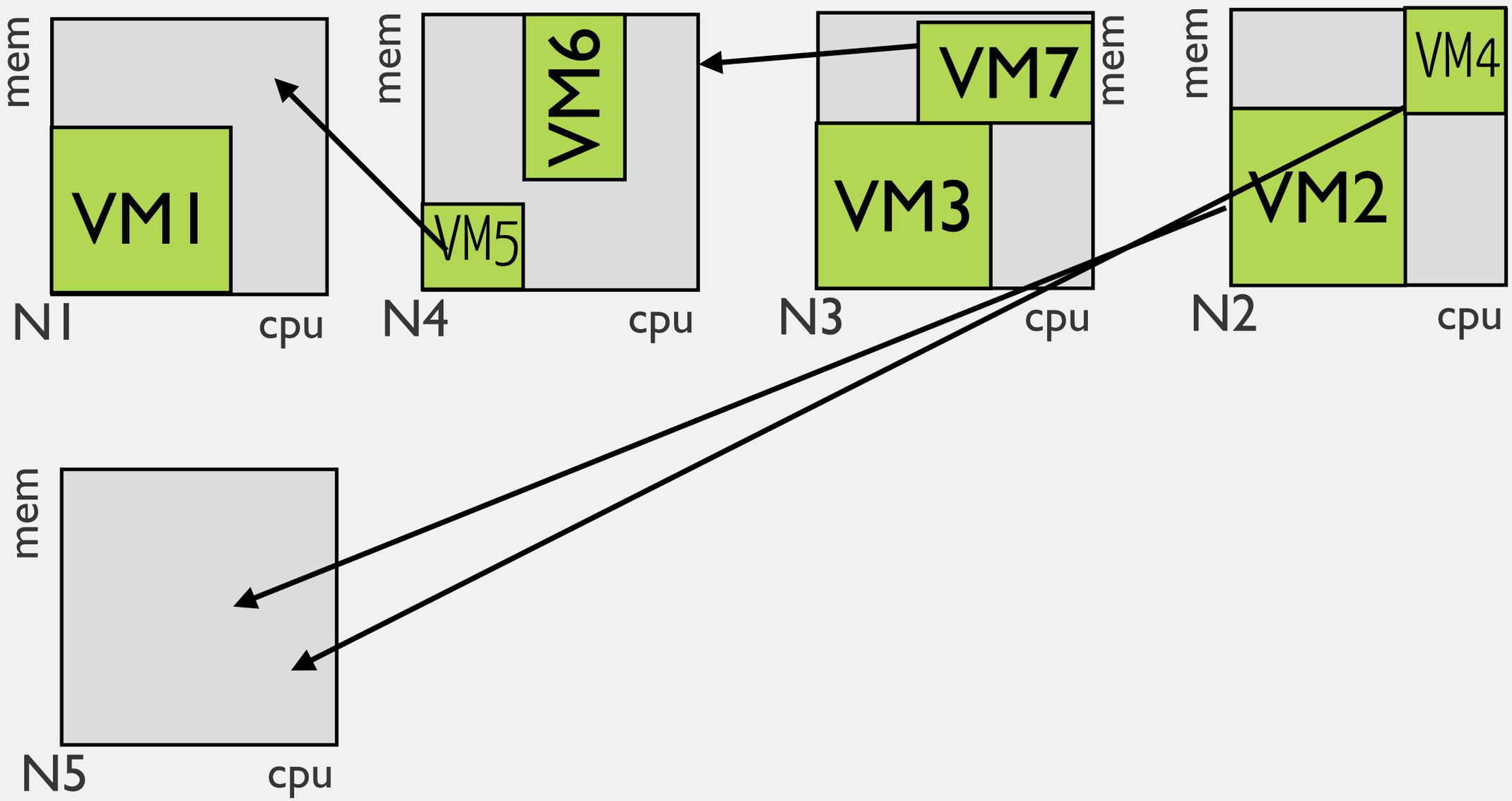
\+ compute dependencies step by steps

ok to implement

/!\ cycles #migrations

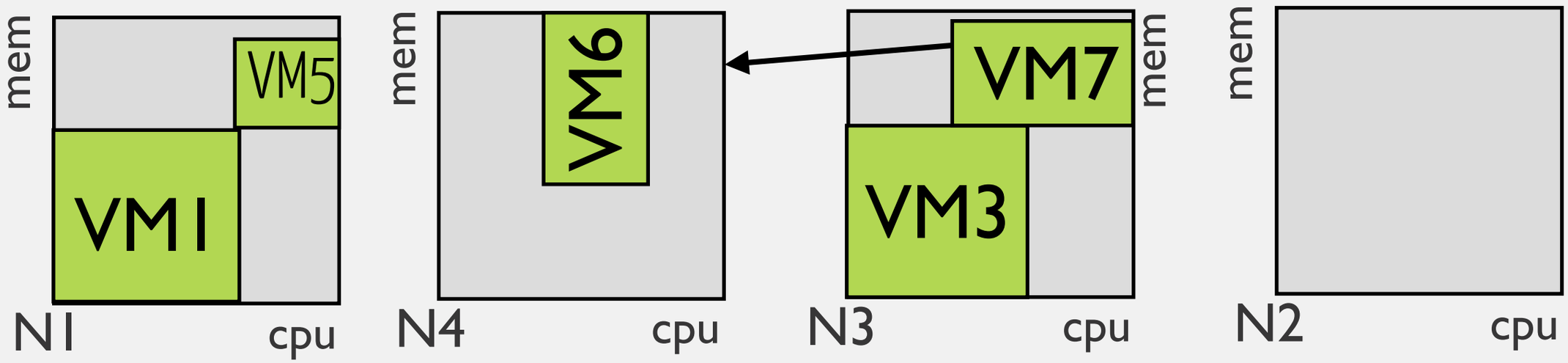
how to support migrations

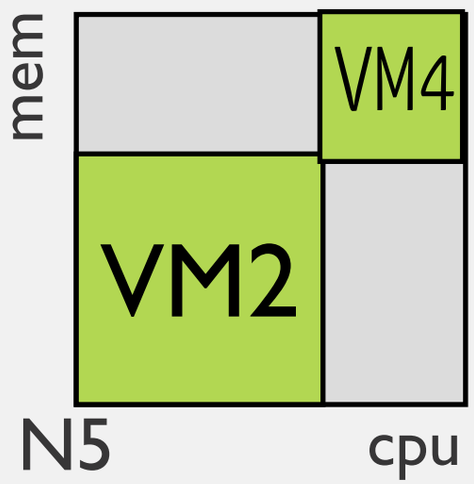
the alternative way



how to support migrations

the alternative way

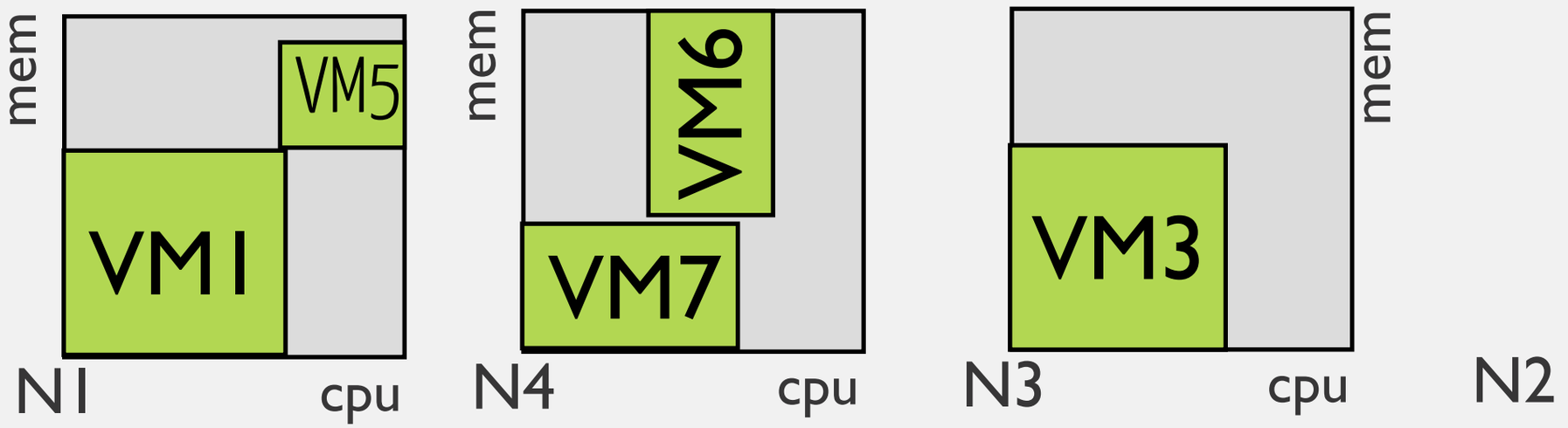


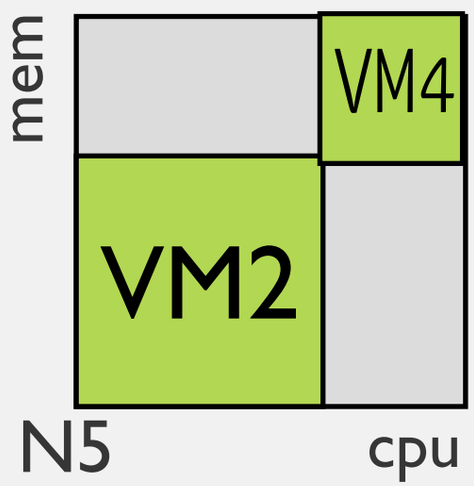


1) migrate VM2, migrate VM4, migrate VM5

how to support migrations

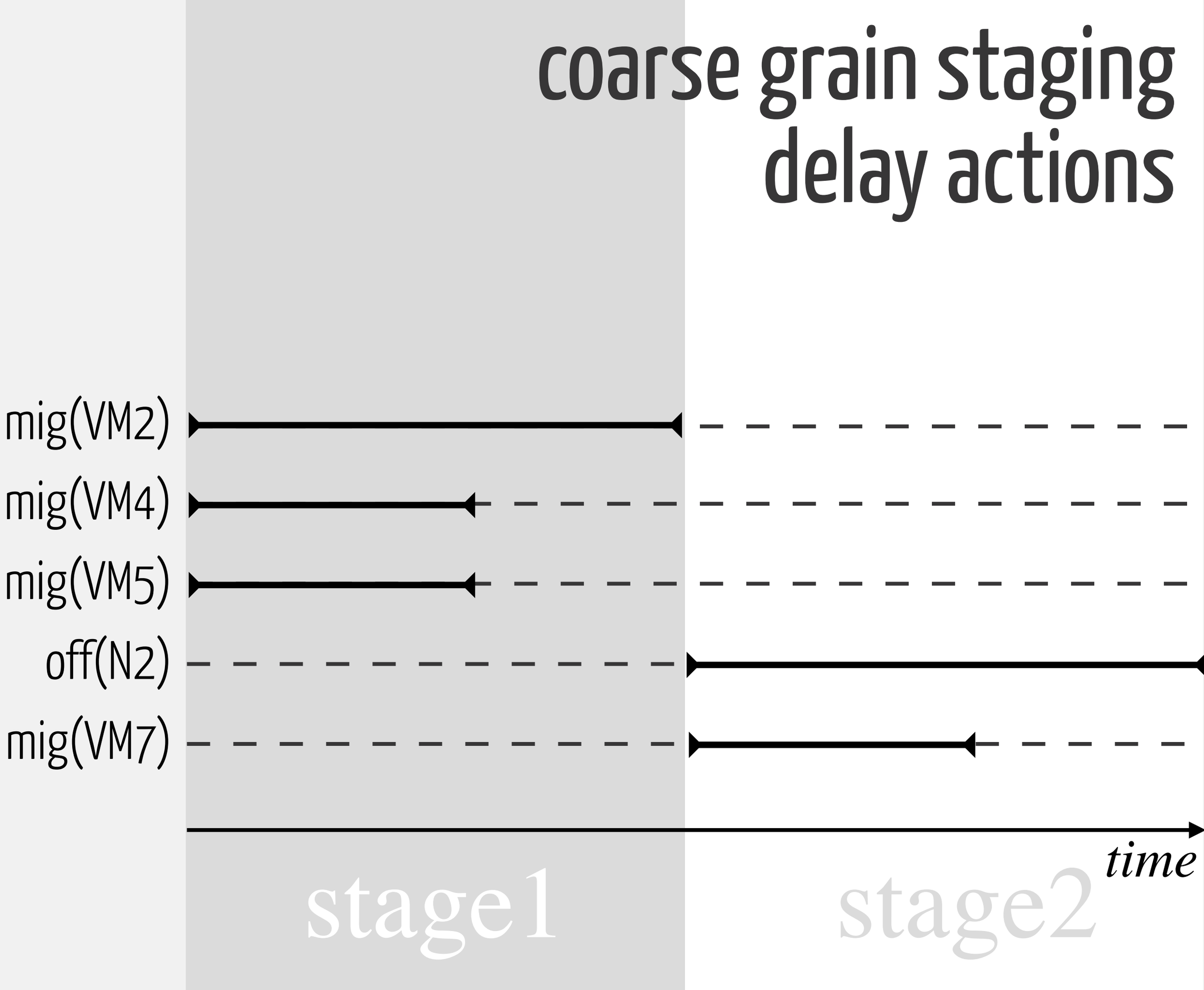
the alternative way





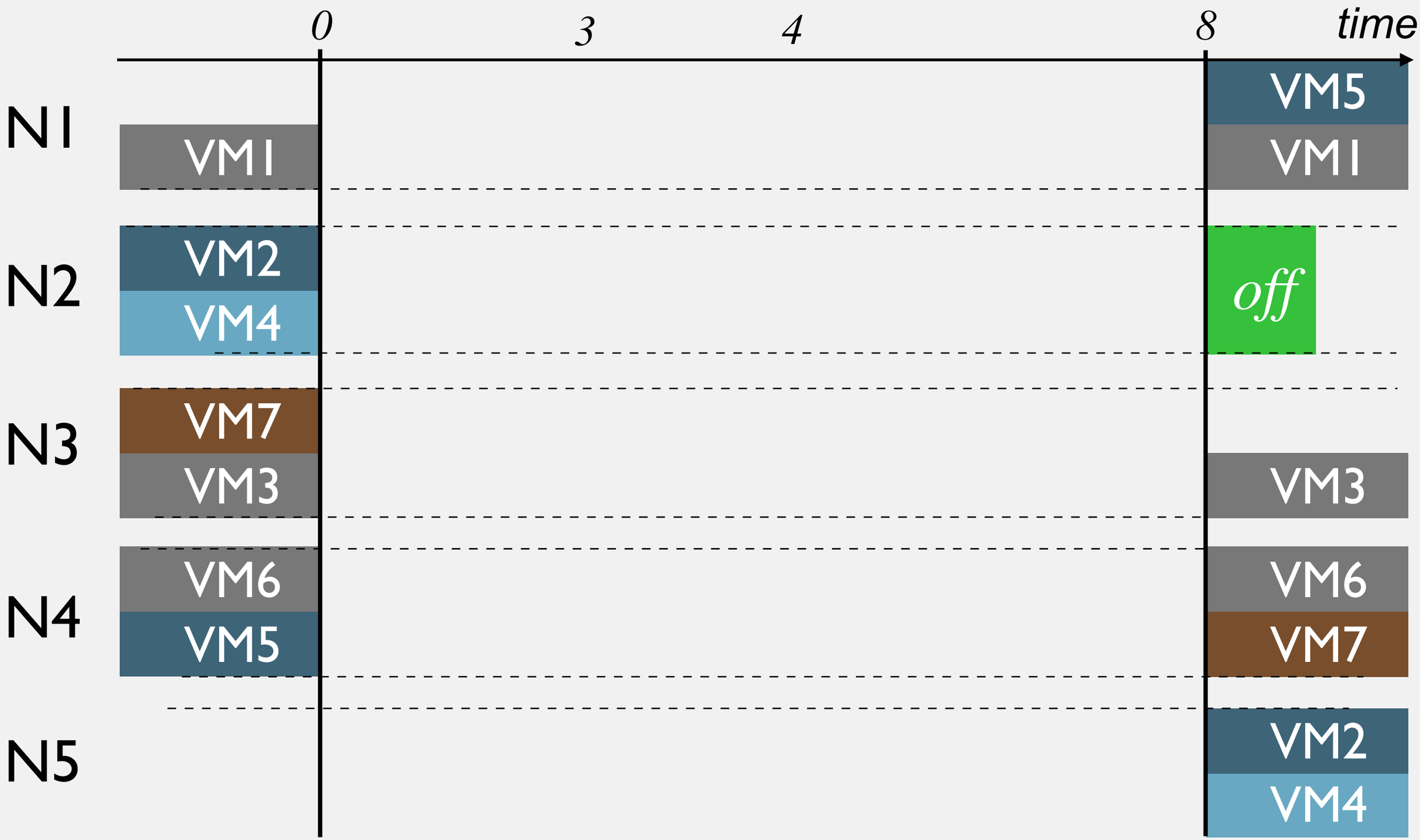
1) migrate VM2, migrate VM4, migrate VM5
2) shutdown(N2), migrate VM7

coarse grain staging delay actions



Resource-Constrained Project Scheduling Problem

the clean way to model space and time



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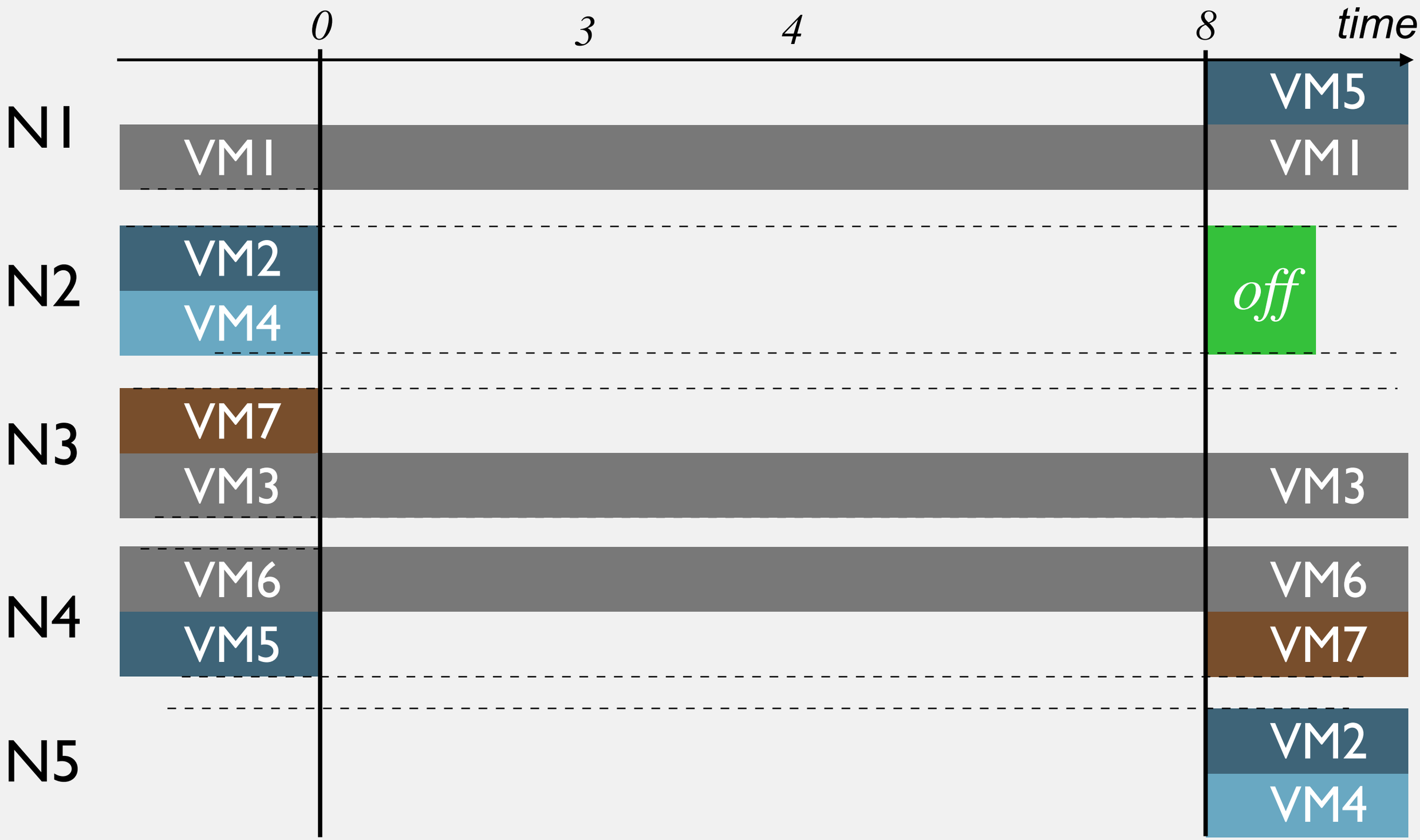

Resource-Constrained Project Scheduling Problem

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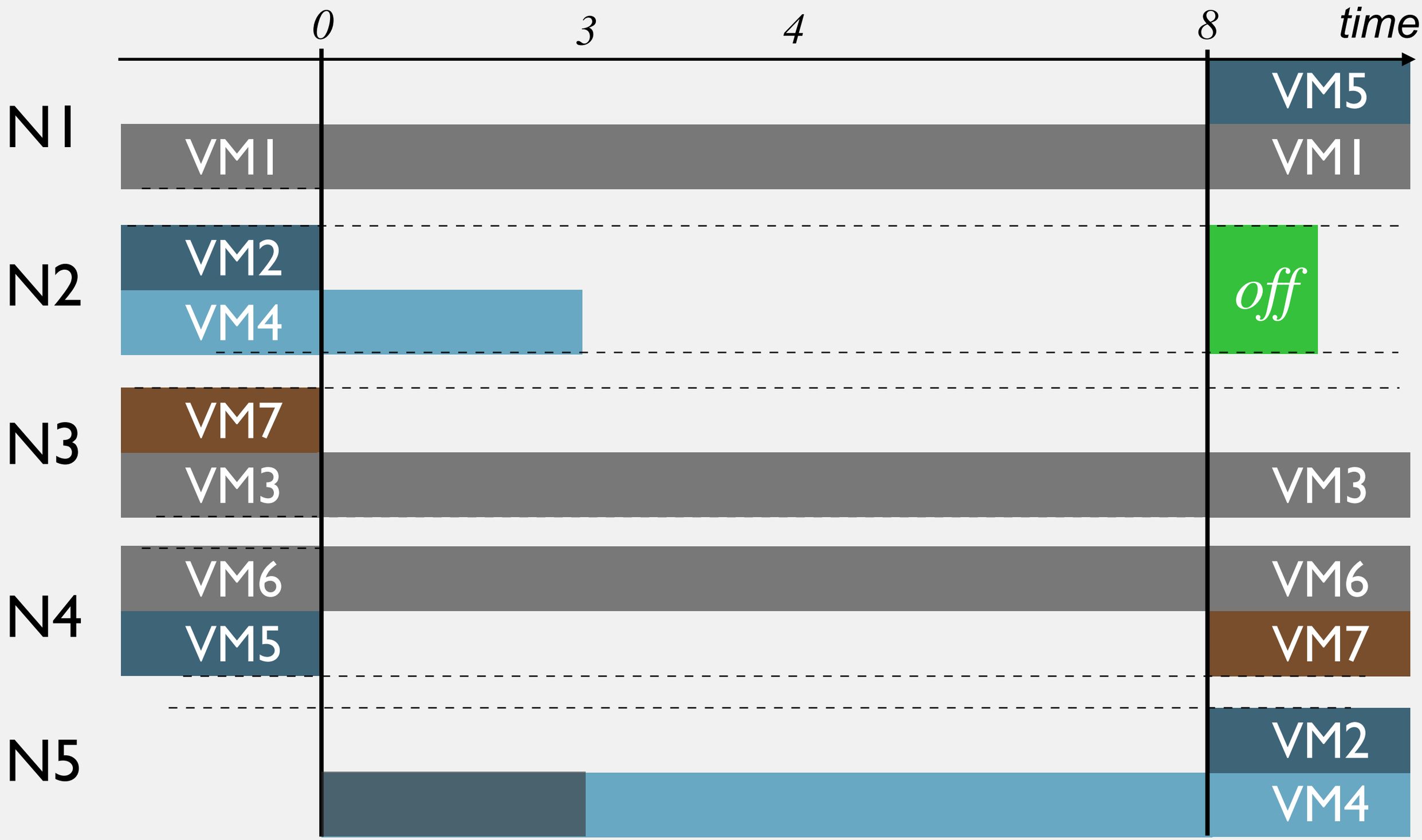

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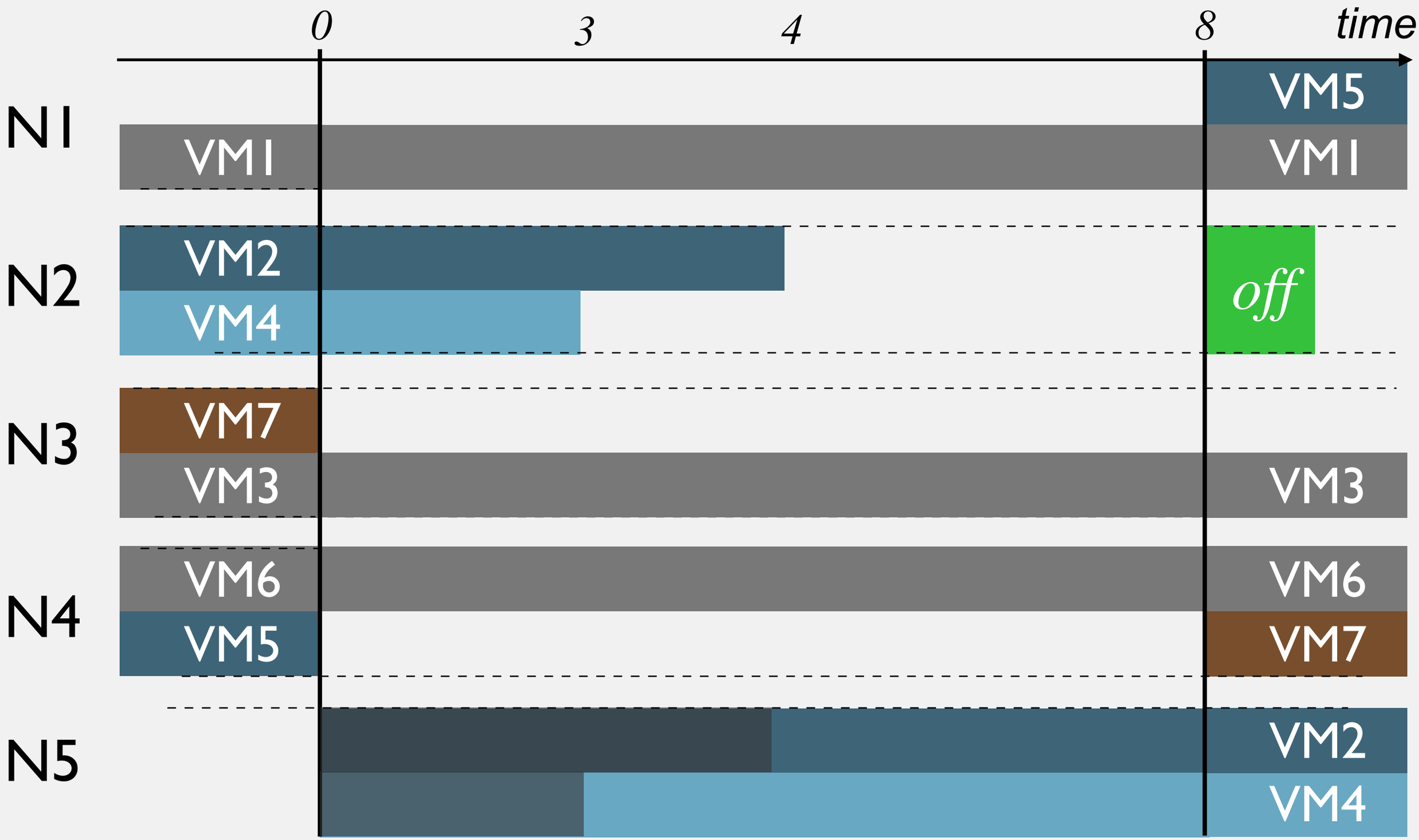

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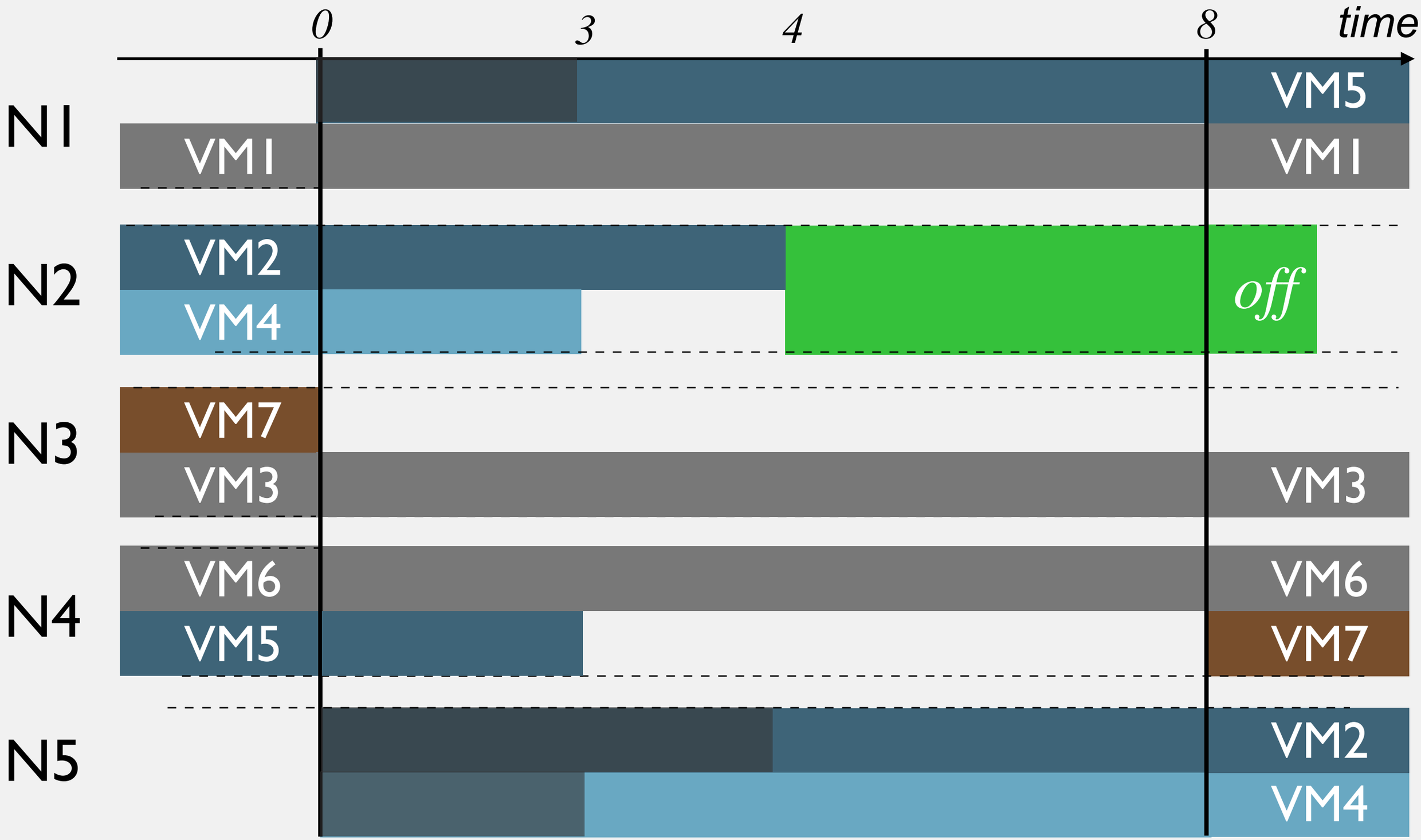
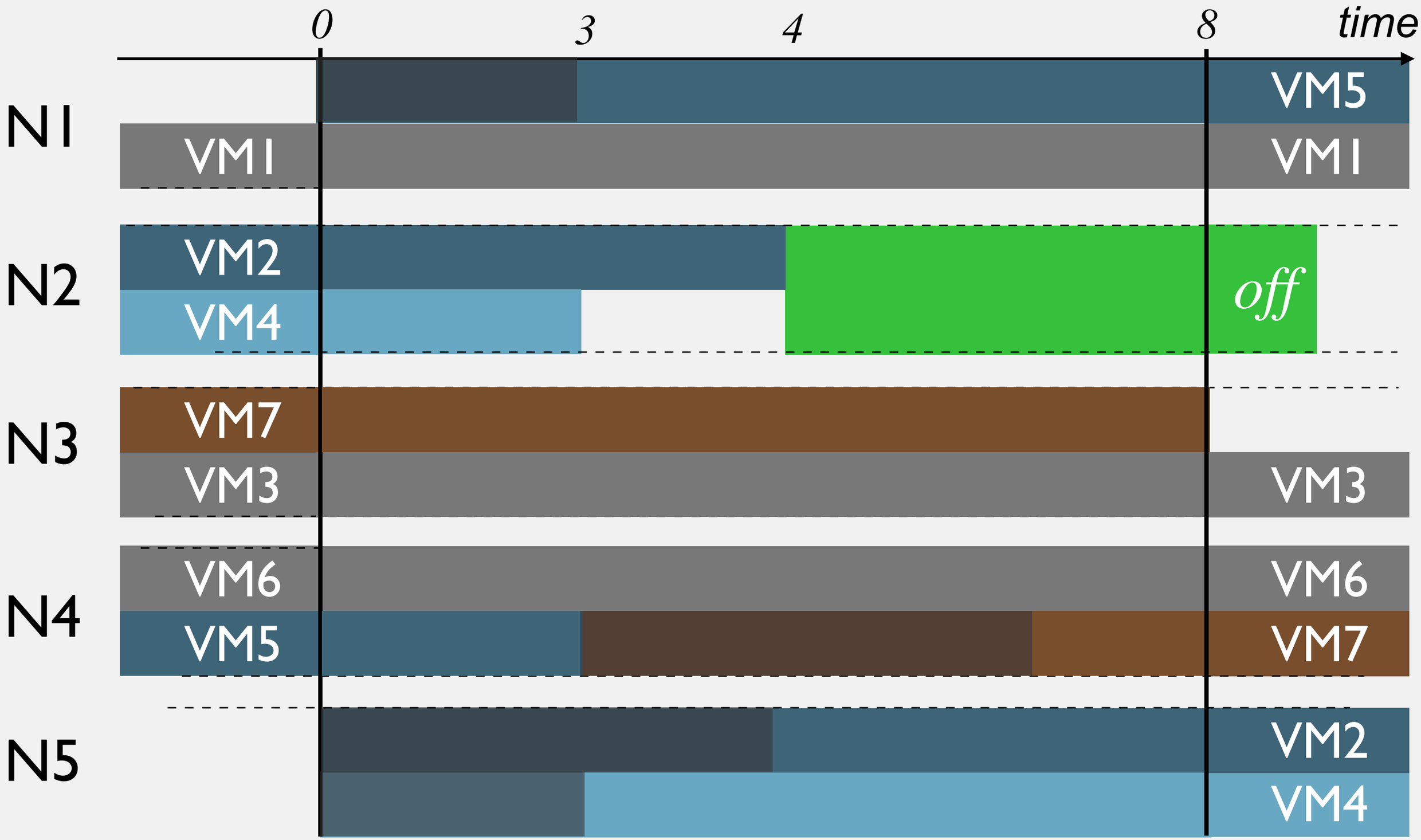
the clean way to model space and time



Resource-Constrained Project Scheduling Problem

the clean way to model space and time



Resource-Constrained Project Scheduling Problem

the pure way to support migrations

1 resource per (node x dimension), bounded capacity

tasks to model the VM lifecycle.
height to model a consumption
width to model a duration

at any moment, the cumulative task consumption on a resource cannot exceed its capacity

comfortable to express continuous optimisation

very hard to implement (properly)

From a theoretical schedule to a practical one

duration may be longer

convert to an event based schedule

0:3 - migrate VM4
0:3 - migrate VM5
0:4 - migrate VM2
3:8 - migrate VM7
4:8 - shutdown(N2)

- : migrate VM4
- : migrate VM5
- : migrate VM2
!migrate(VM2) & !migrate(VM4): shutdown(N2)
!migrate(VM5): migrate VM7

Back to vector packing based approaches

Fit Fit Decrease (FFD)

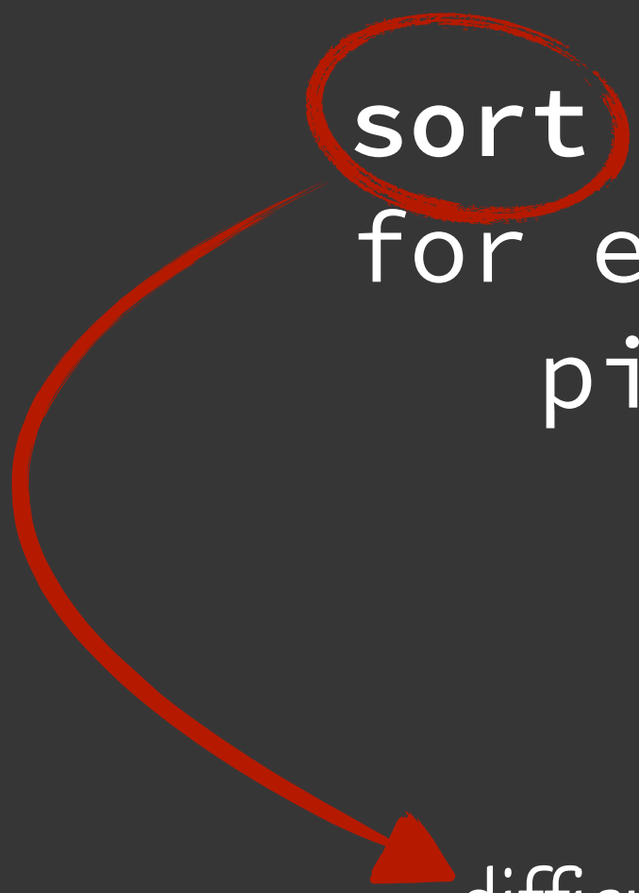
basic VM scheduling

```
sort VMs in desc order
for each VM
    pick the first suitable node
```

Fit Fit Decrease (FFD)

basic VM scheduling

```
sort VMs in desc order
for each VM
    pick the first suitable node
```



difficult VMs first !

Fit Fit Decrease (FFD)

basic VM scheduling

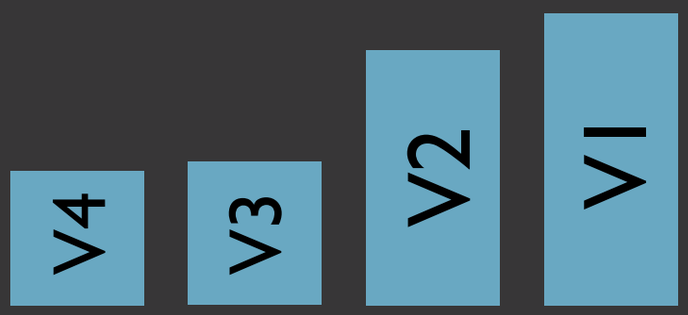
```
sort VMs in desc order
for each VM
    pick the first suitable node
```

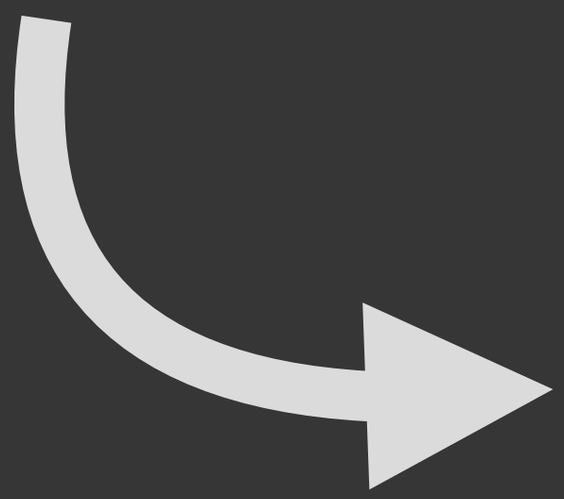
difficult VMs first !

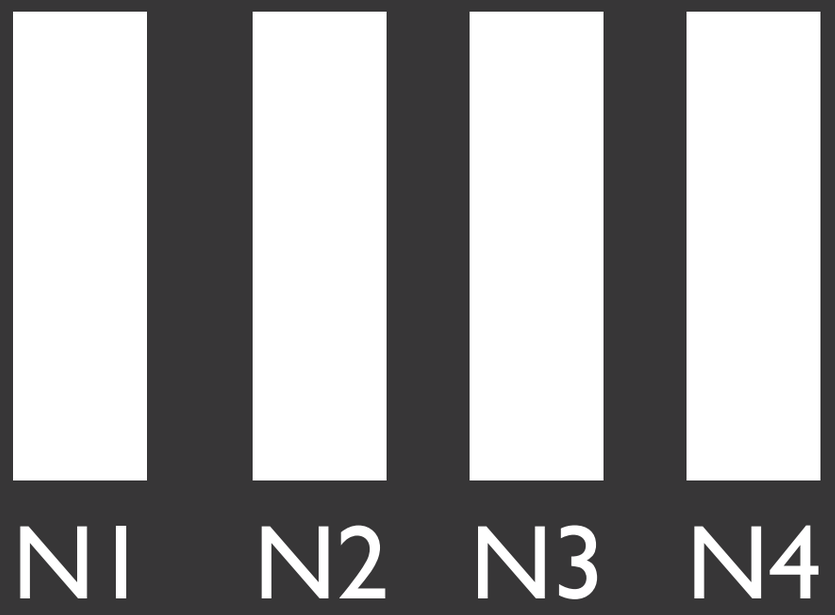
enough free resources

Fit Fit Decrease (FFD)

example

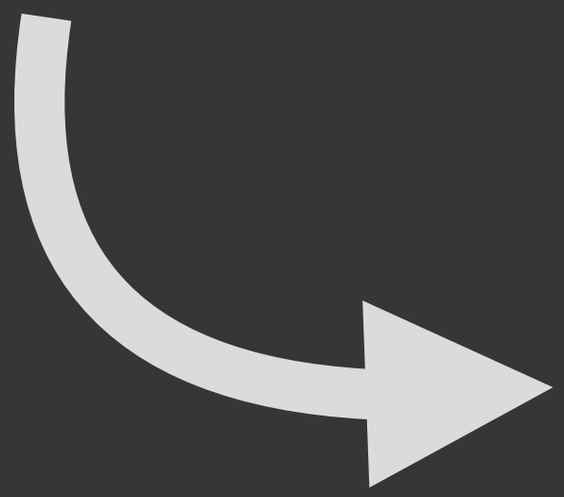


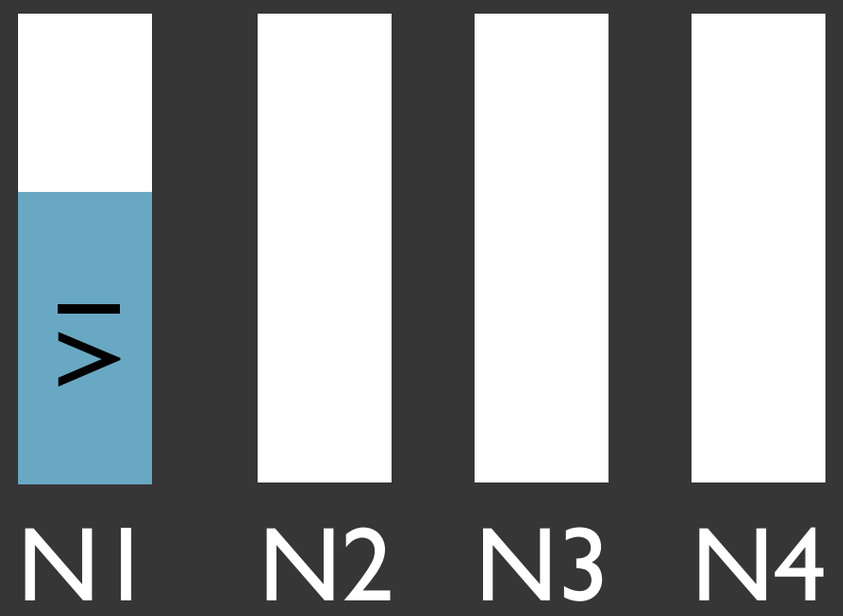




Fit Fit Decrease (FFD)

example



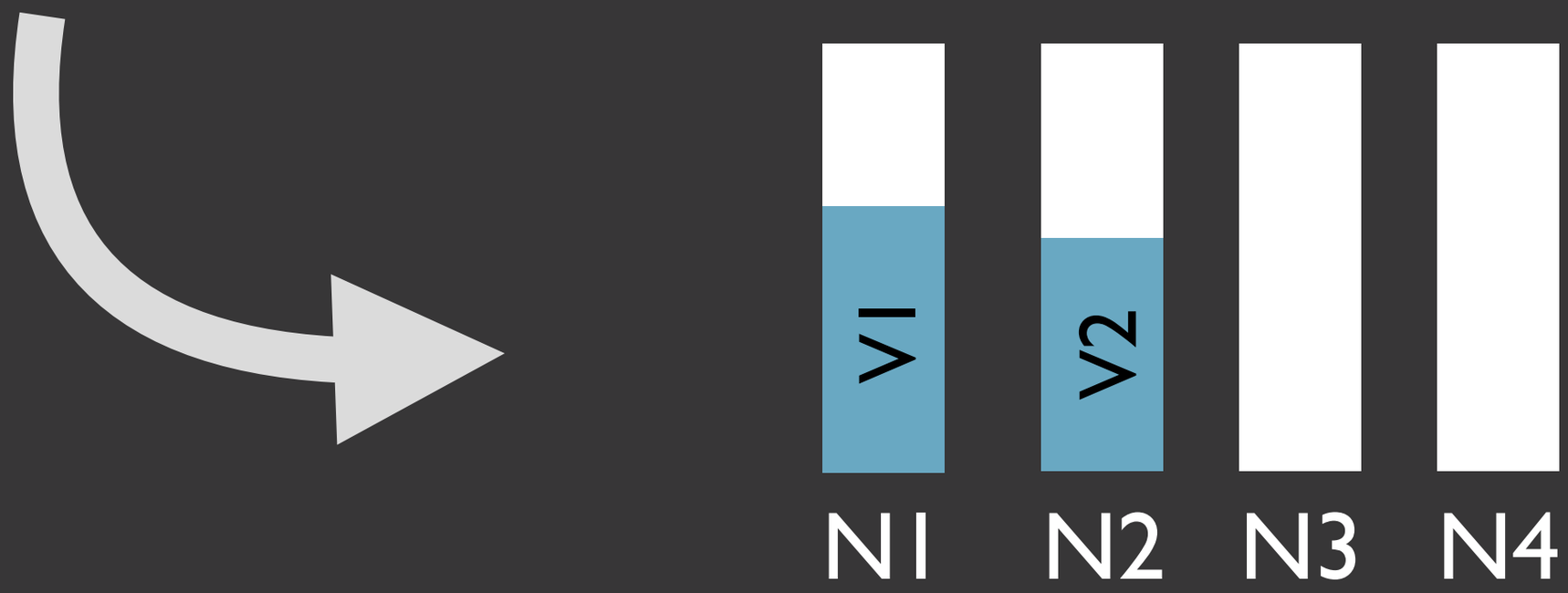


Fit Fit Decrease (FFD)

example

V4

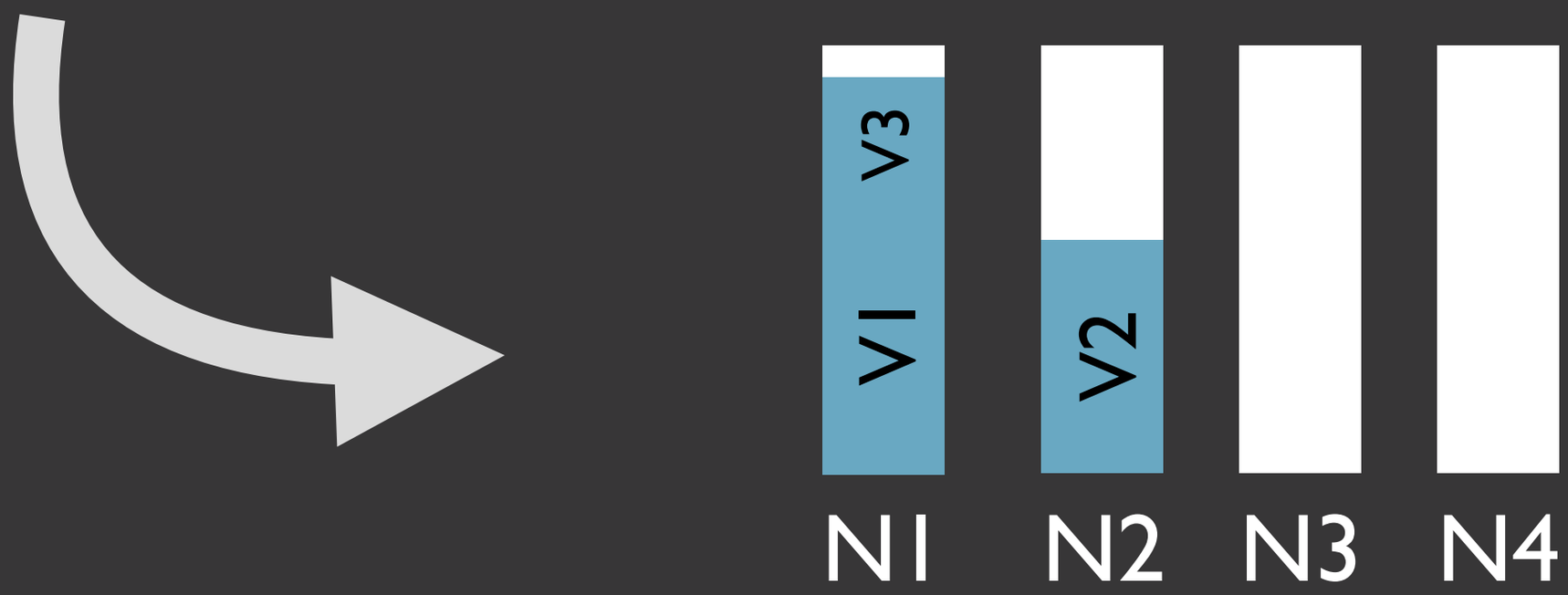
V3



Fit Fit Decrease (FFD)

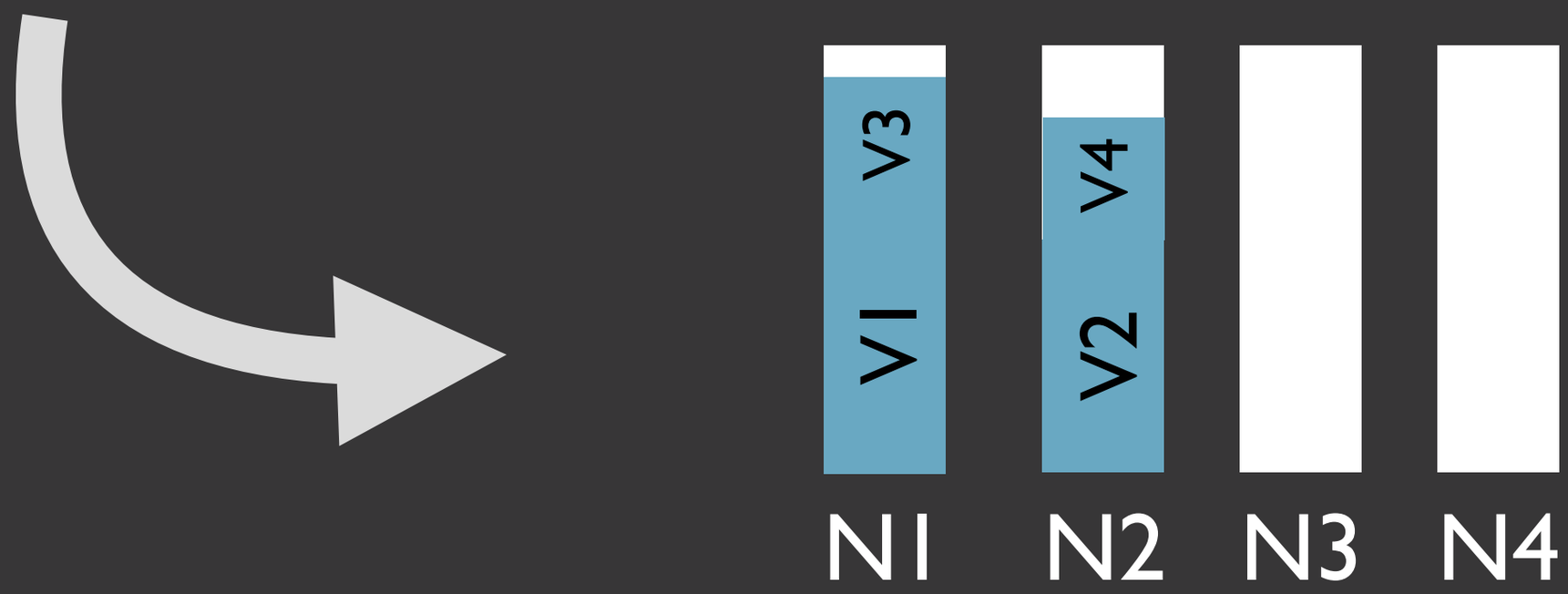
example

V4

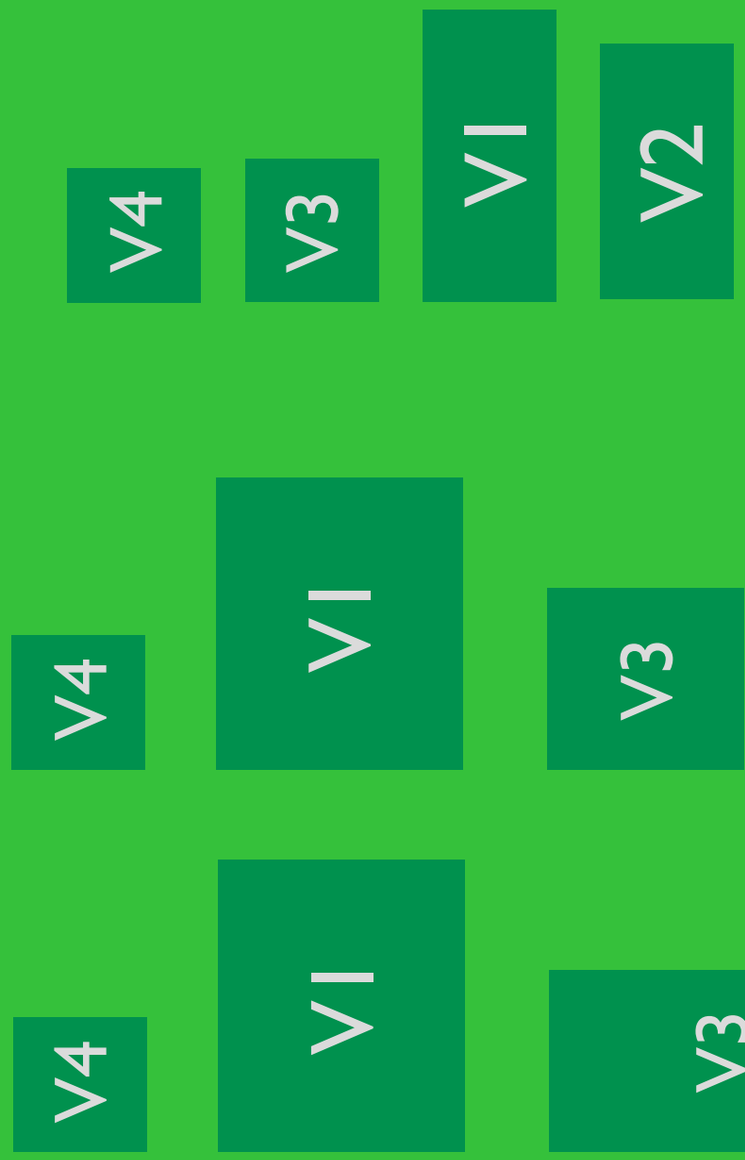


Fit Fit Decrease (FFD)

example



multi-dimension sorting ?



easy, 1 dimension is varying

easy, uniform variation

?

multi-dimension sorting ?

easy, 1 dimension is varying

easy, uniform variation

sort by dimension
aggregate dimensions
find the most critical one

...

Balancing VMs

Why?

Why?

to reduce loss in terms of failures
to reduce hotspots
to absorb load spikes

balancing

in theory

$$min(stddev([load(n_1), \ldots, load(n_i)]))$$

OR

$$min(\\ max([load(n_1), \ldots, load(n_i)]),\\ min([load(n_1), \ldots, load(n_i)]),\\ )$$

Worst Fit Decrease (WFD)

balancing, a practice

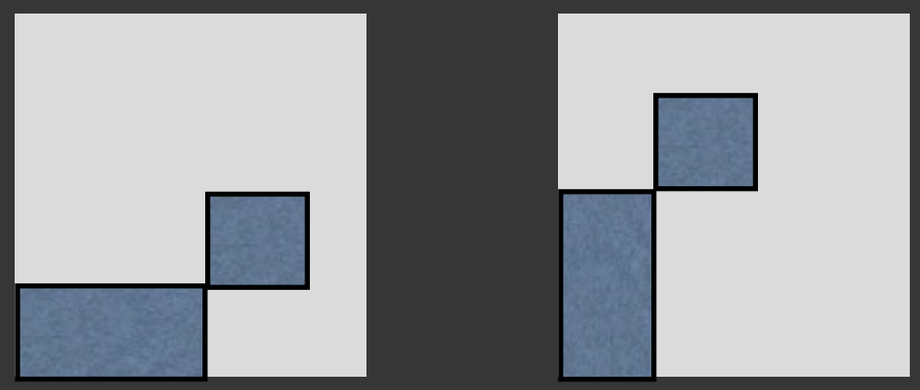
```
sort VMs in desc order
for each VM
    pick the suitable node
         with the highest remaining
         space
```

?

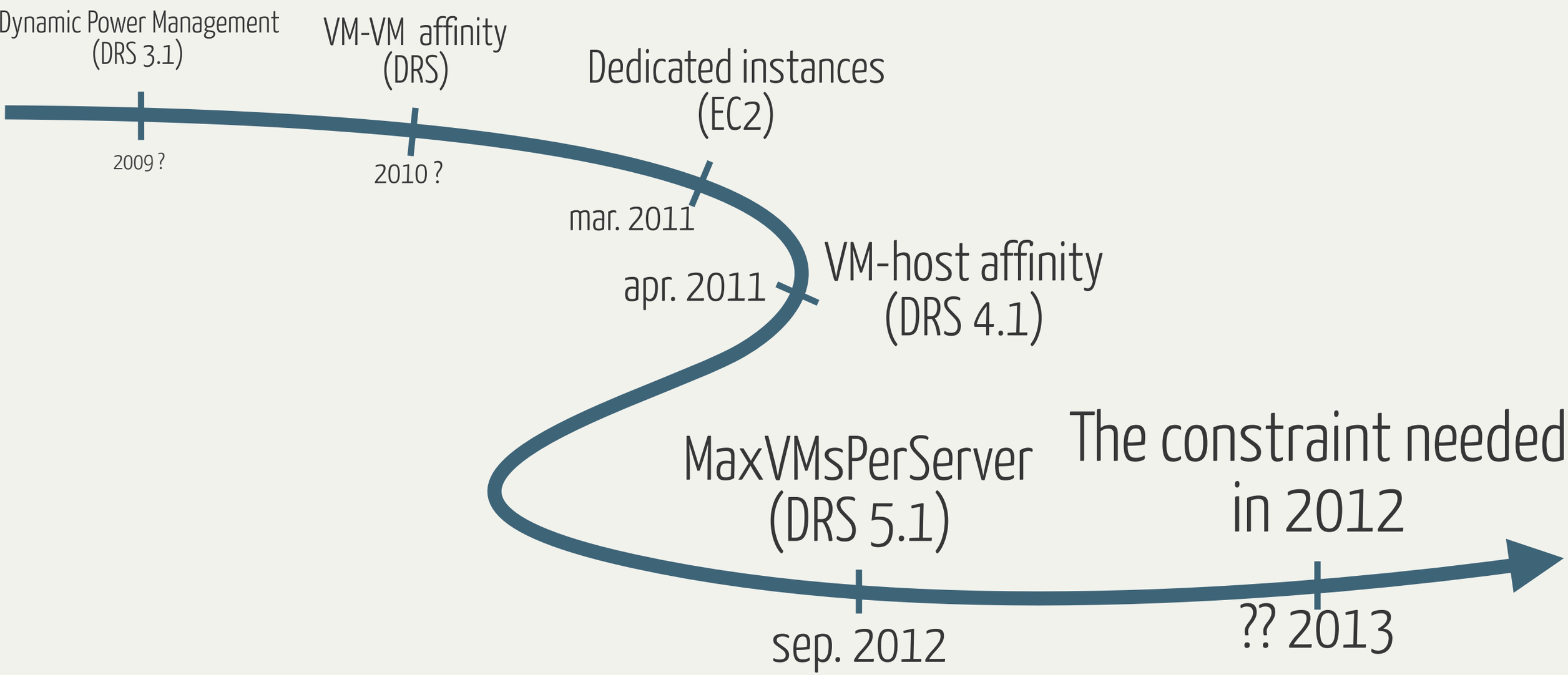
balancing over
multiple dimensions

balancing over multiple dimensions

dimension normalisation
worst dimension
dimension aggregation
current state vs. next state



What about the SLOs ?



SLOs inject additional rules

placement constraint

(anti)affinity rules

fault tolerance, hw. compatibility, security

VM-VM, VM-PM, relative, absolute

temporal constraint

precedences, parralelism, sequence

control, performance

control between actions

counting constraint

performance, licensing restriction

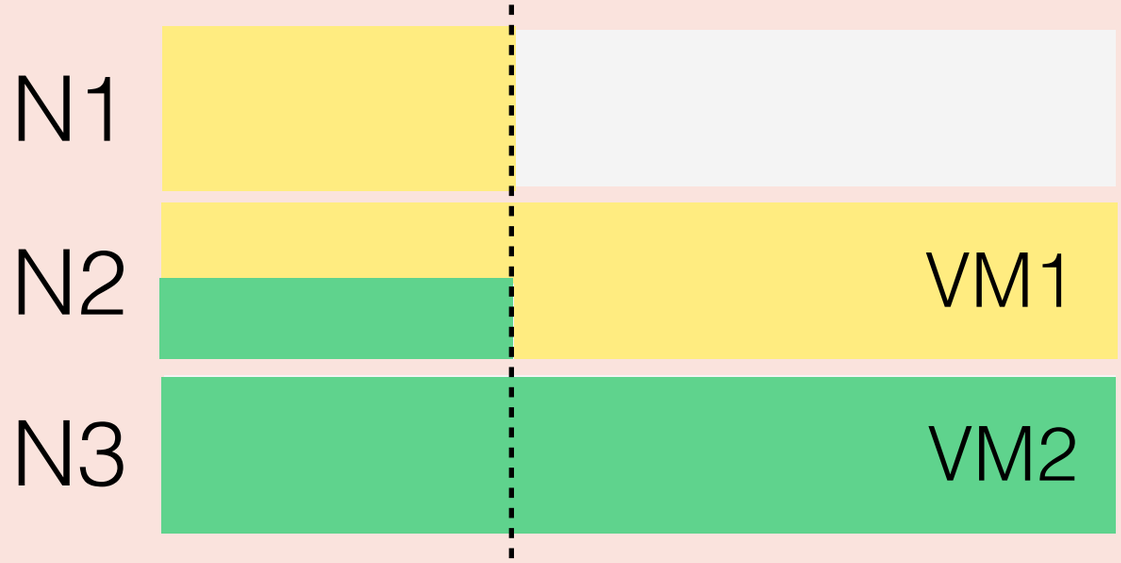
per node, group of nodes, resource

...

...

discrete constraints

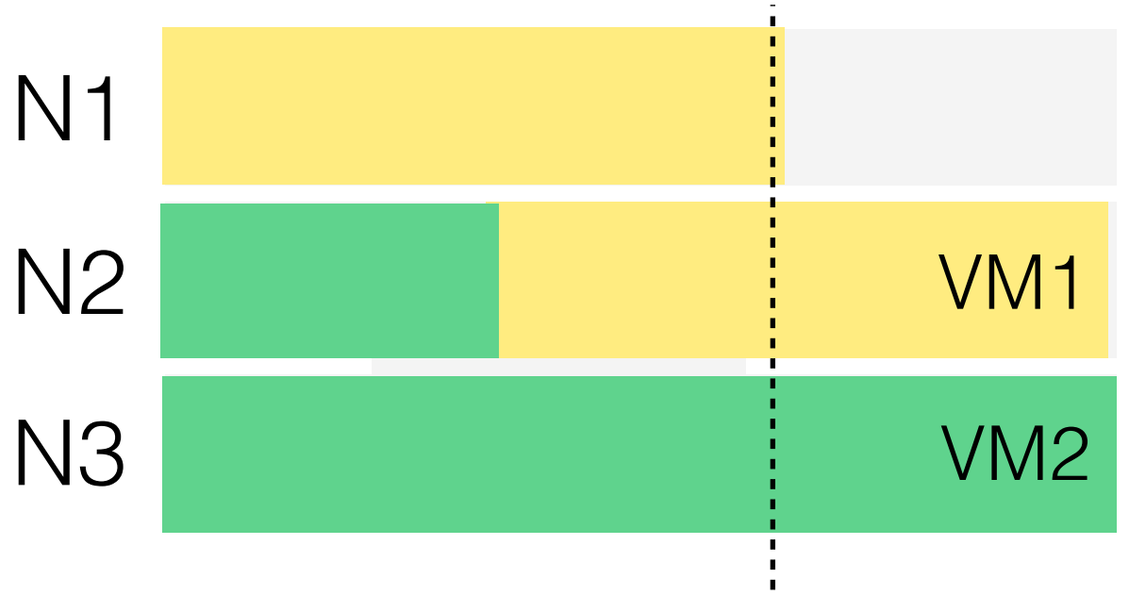
```
>>spread(VM[1,2])
ban(VM1, N1)
ban(VM2, N2)
```



"simple" spatial problem

continuous constraints

```
spread(VM[1,2])
ban(VM1, N1)
ban(VM2, N2)
```



harder scheduling problem
(think about actions interleaving)

hard constraints

```
spread(VM[1..50])
```

must be satisfied
all or nothing approach
not always meaningful

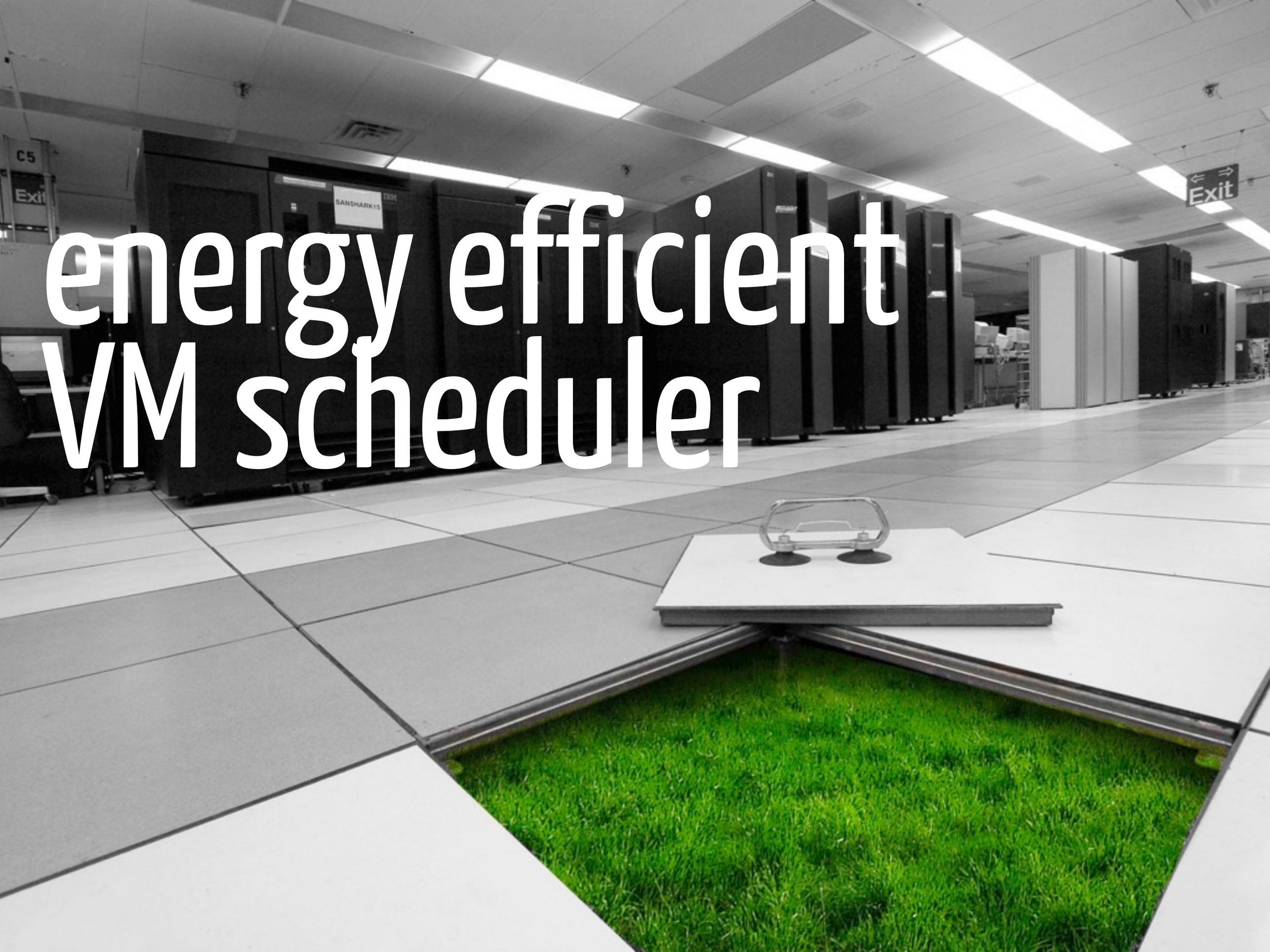
soft constraints

```
mostlySpread(VM[1..50], 4, 6)
```

satisfiable or not
internal or external penalty model

harder to implement/scale
hard to standardise ?

energy efficient VM scheduler



1.5%

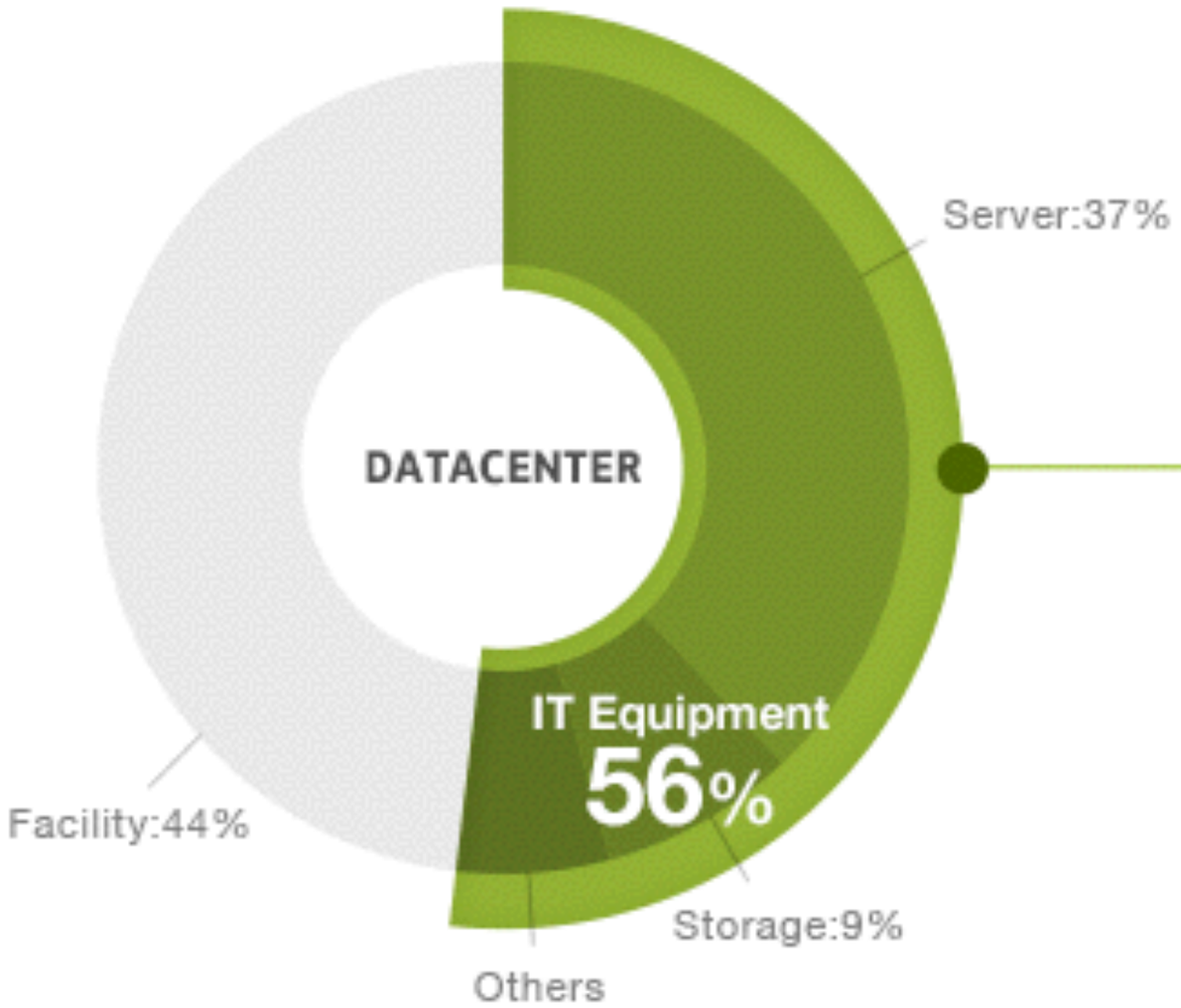
of the 2005 budget

3 %

in 2010 ?

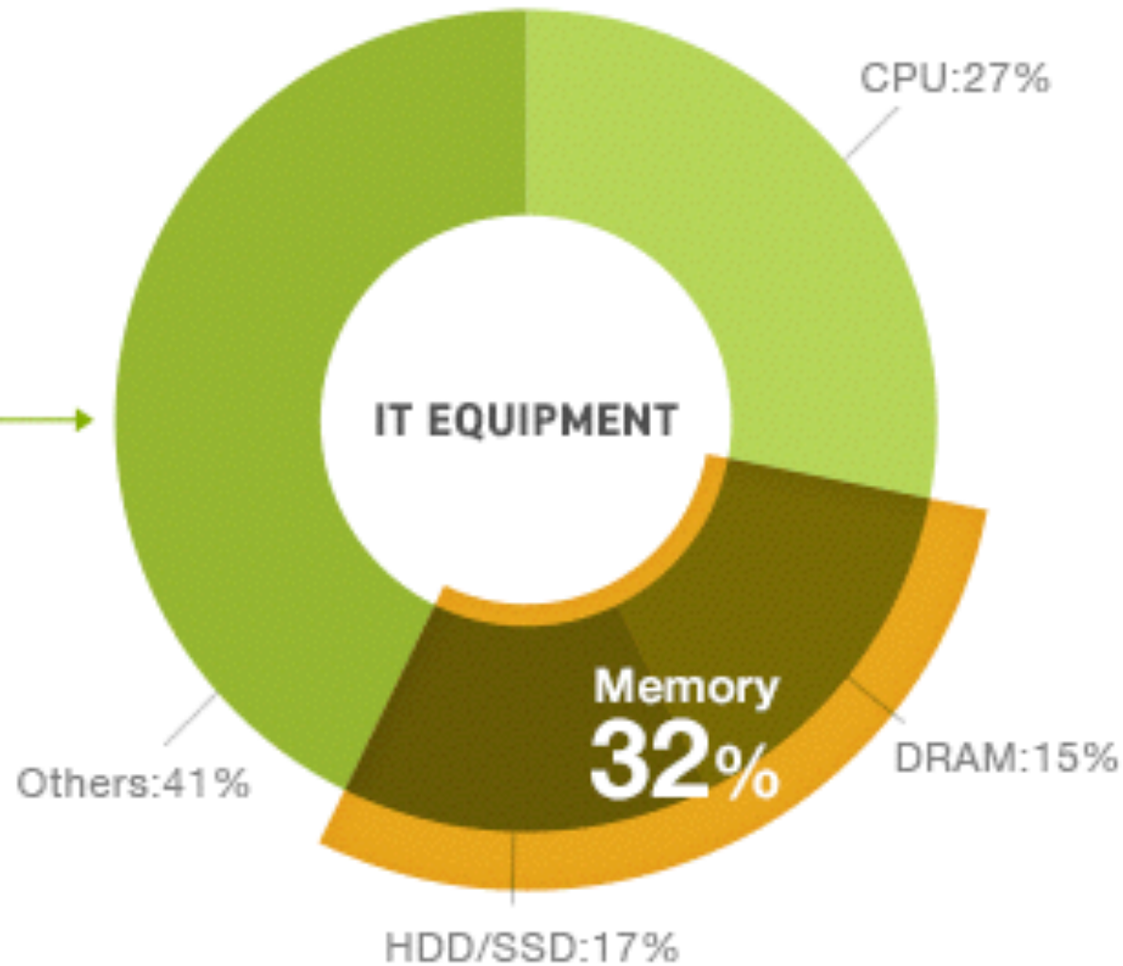
(Environmental Protection Agency, 2007)

DATACENTER POWER CONSUMPTION



Source: Uptime Institute's 2012 Data Center Survey
J. Koomey's Report, Aug 2011

IT EQUIPMENT POWER DRAW



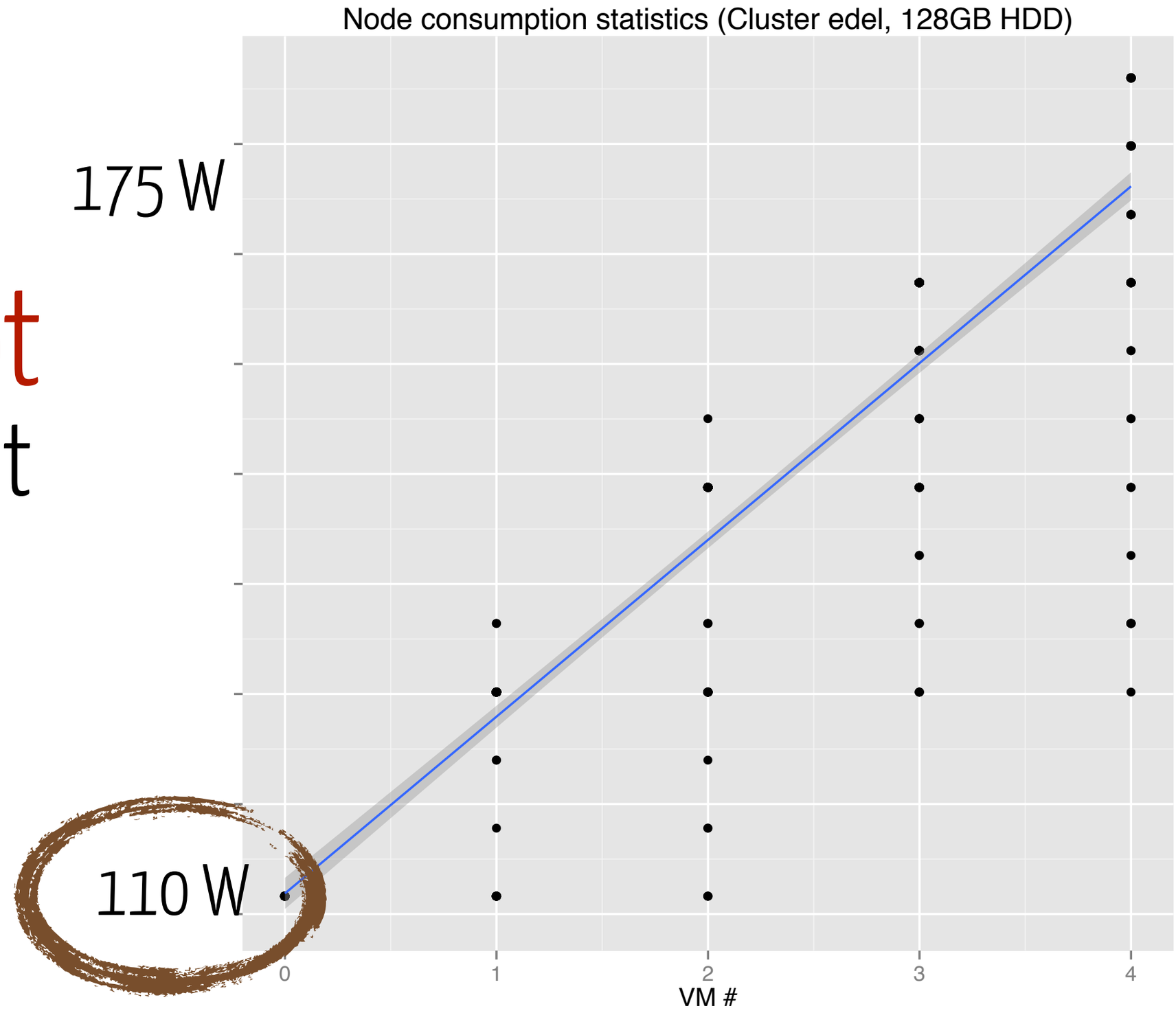
Source: Samsung, IDC, EMC

1

Consume less

2003

servers are not energy efficient



how to reduce consumption with identical nodes

?

The principles

place VMs on the minimum number of nodes

turn off idle nodes

rince/repeat for the dynamic version

Best Fit Decrease (BFD)

a simple heuristic to pack VMs

```
sort VMs in desc order
for each VM
    pick the suitable node
         with the least remaining
         space
```

efficiency decreases when nb. of dimensions increase

2-pass dynamic VM packing

to manage the running VMs

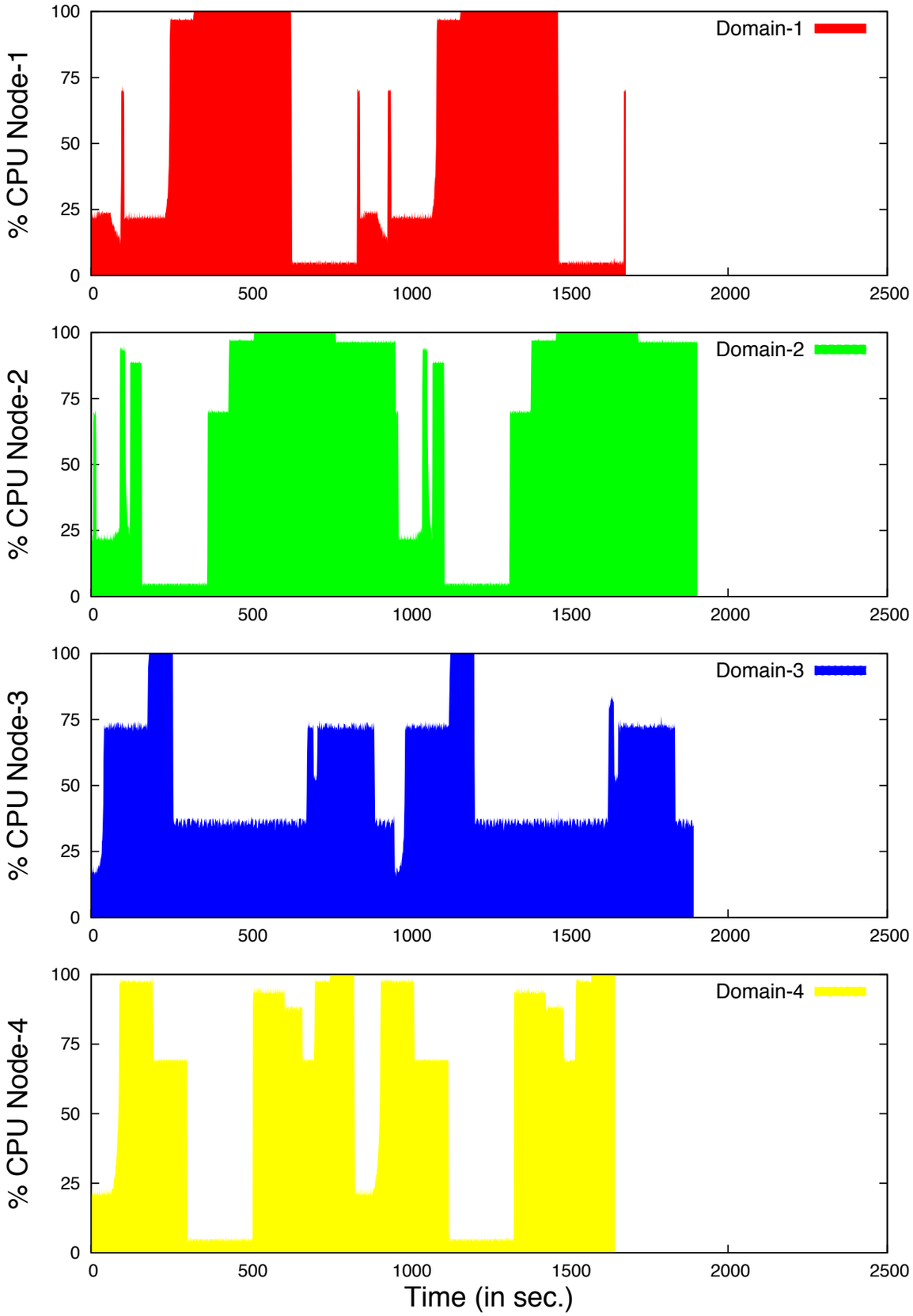
1) address performance issues

on saturated nodes,
BFD to move away VMs on non-saturated nodes

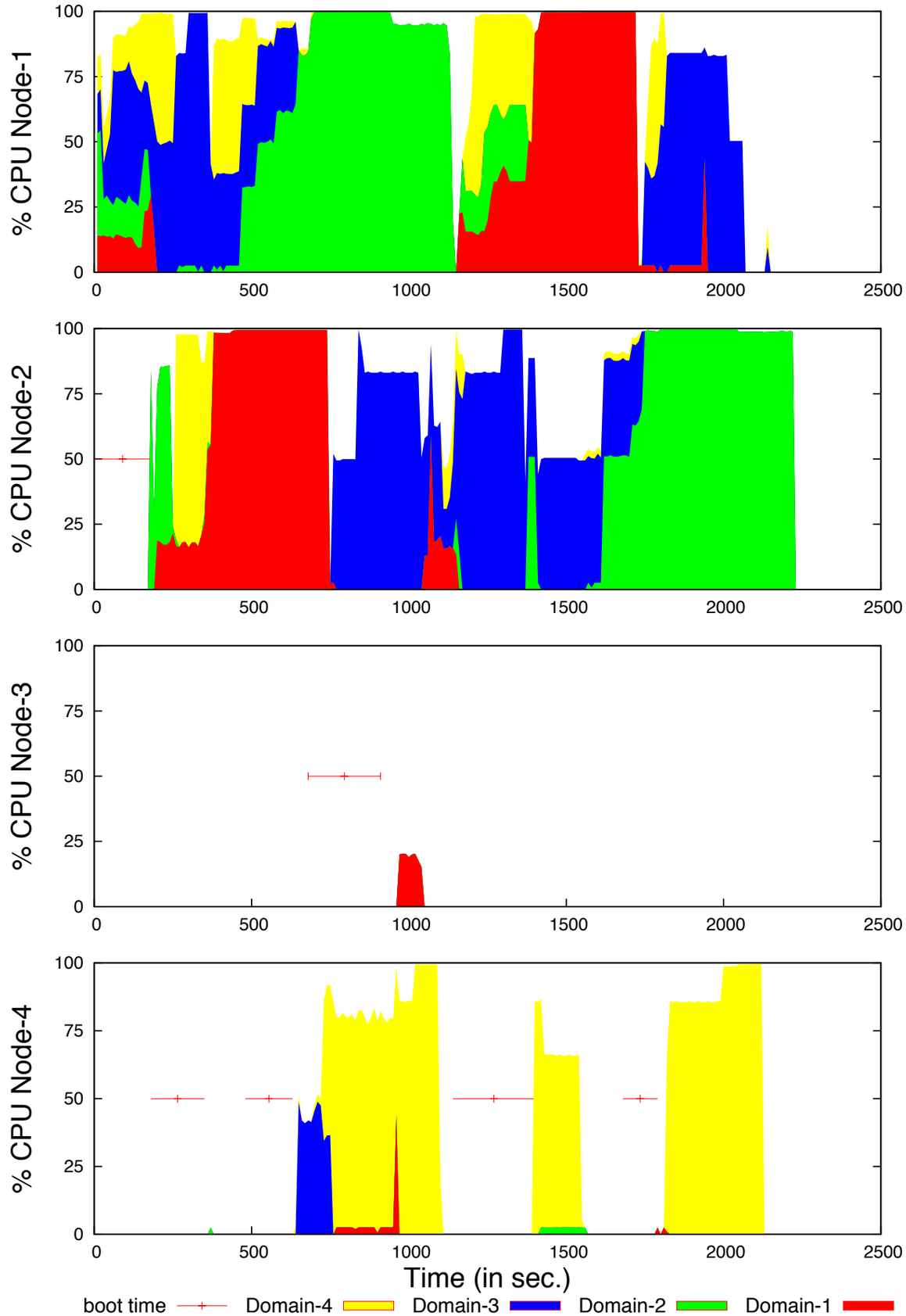
2) address energy efficiency issues

on low-loaded nodes,
BFD to move away VMs on heavily loaded nodes

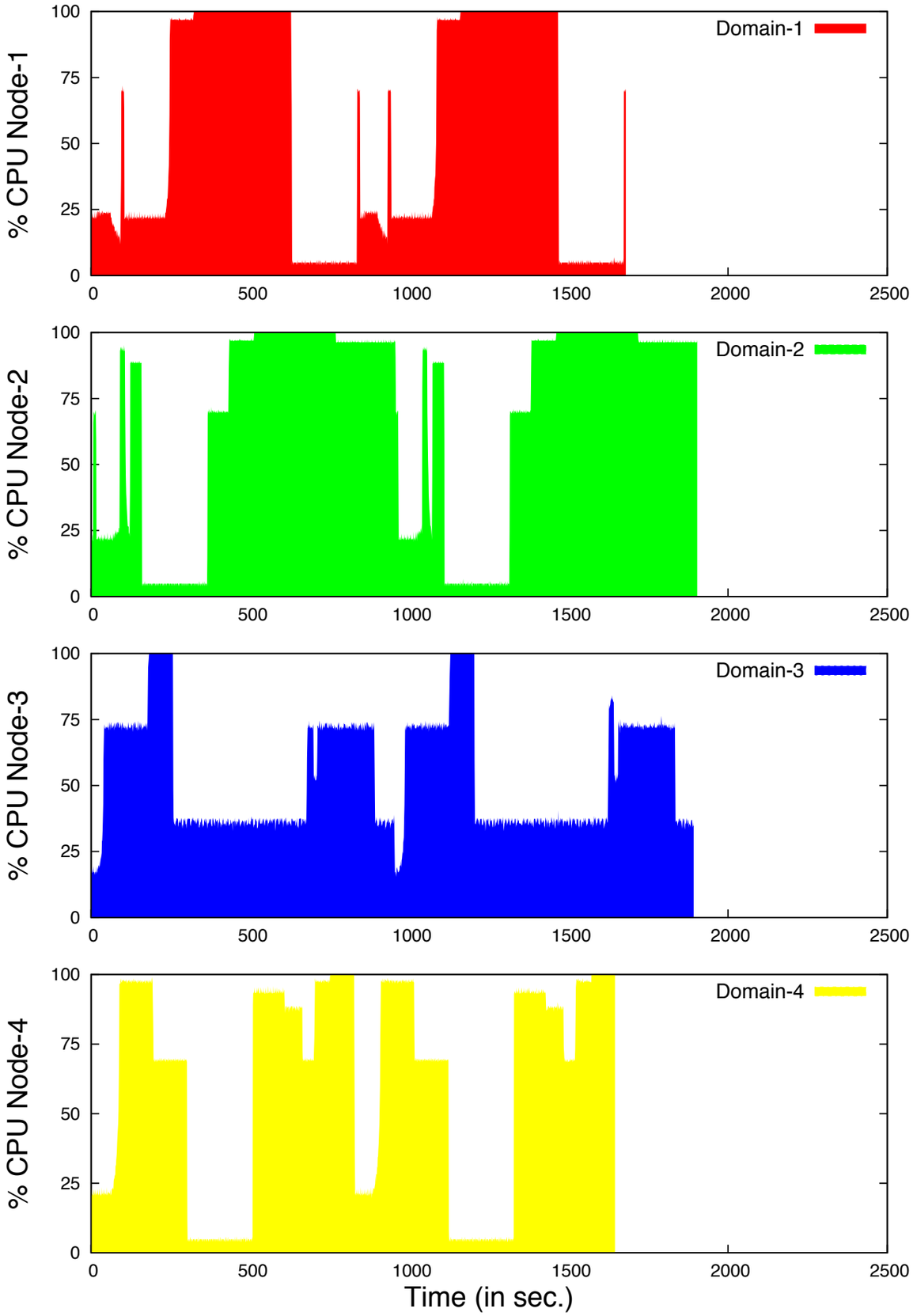
many variations using threshold based systems, load predictions ...



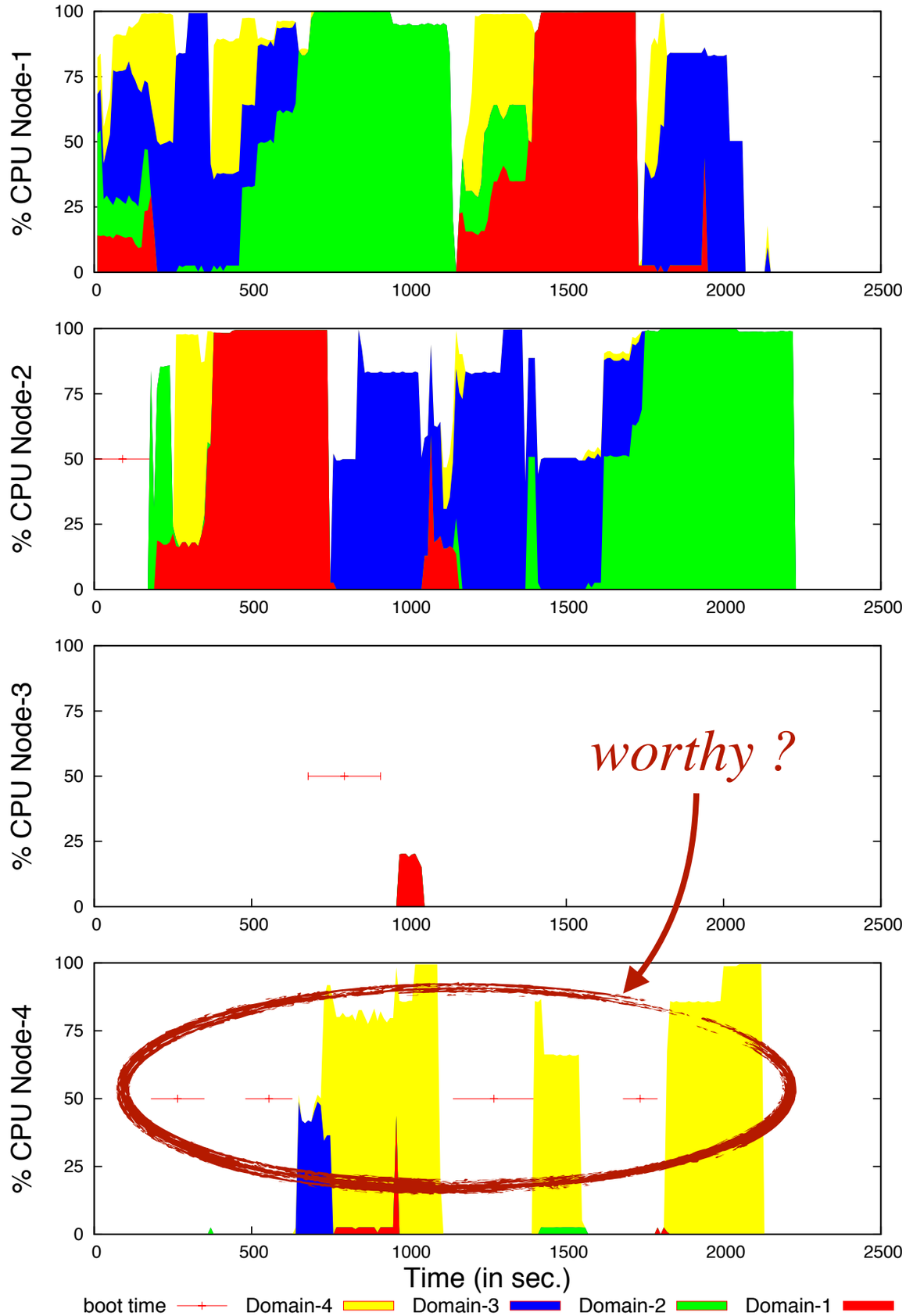
No packing



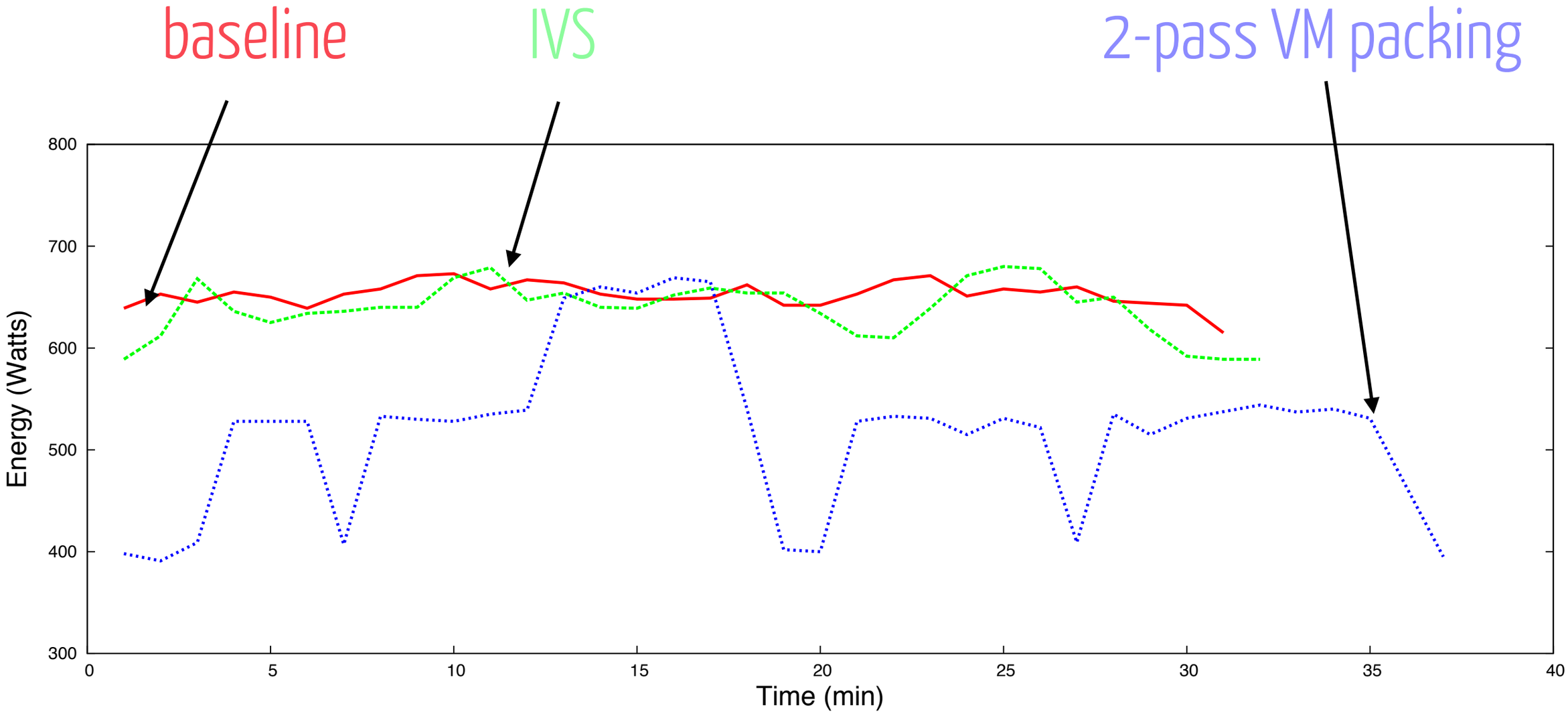
2-passes packing



No packing



2-passes packing



interesting gains,
the node boot time was the bottleneck
simplistic model (identical nodes)

Consequences of having heterogeneous nodes ?

Consequences of having heterogeneous nodes ?

different performance
different Power Usage Effectiveness

...

how to estimate the benefits of a migration ?

vector packing problem
+ performance model
+ power model
+ cost model
+ ...

---

a specialised model

power models

estimate the energy consumption

model the static and the dynamic energy profile of the components

usually linear equations

$$Wh(node) = \alpha\, Hw + \beta$$

VM performance models

a neutral performance unit
mips, ECU, GCU, ...

a model to map
VM performance with their host

$$perf(VM, N) = \alpha_n \%cpu + \beta$$

hw. particularities

multi-core CPUs,
DDR3 memory,
spinning HD,
PUE / CUE,
boot/shutdown time

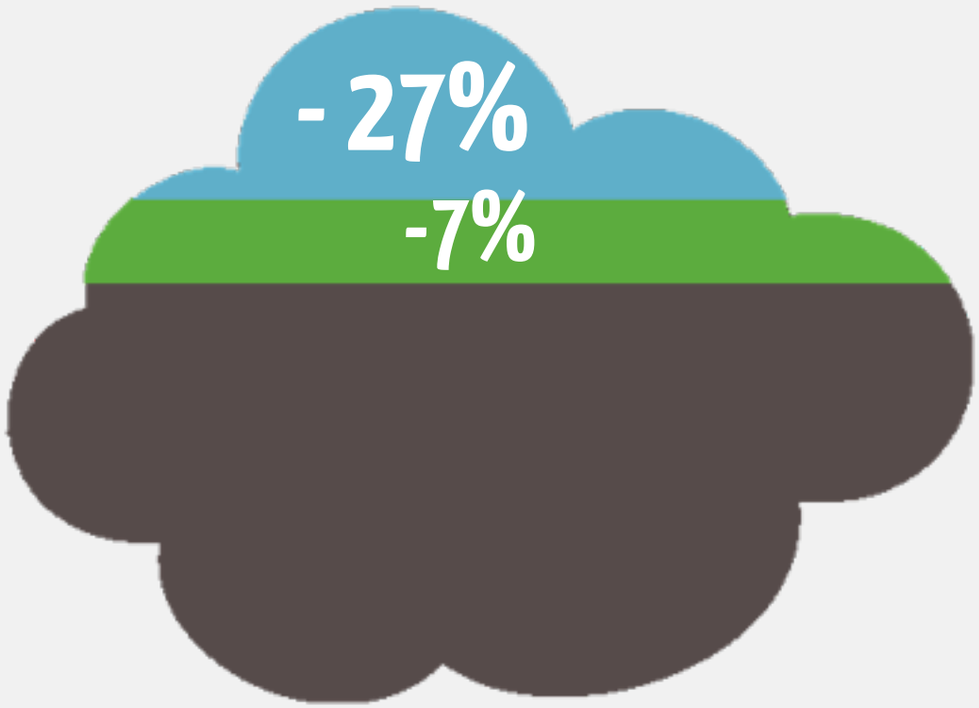
FIT 4 GREEN

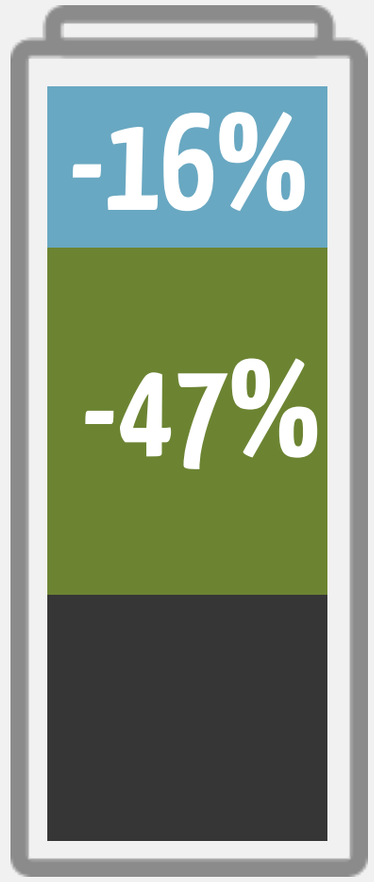
workload particularities

VM template
migration duration
migration payback time

a fine-grain power model

FIT 4 GREEN





coarse to fine
grain optimisation

Consume better

2012

from a spatial to a temporal point of view

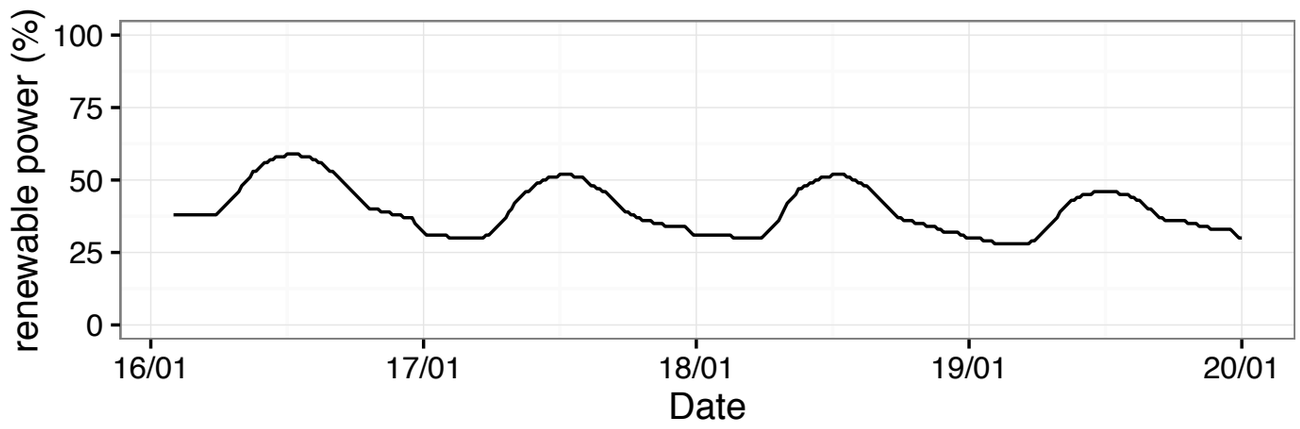
SEVENTH FRAMEWORK PROGRAMME

DC4Cities

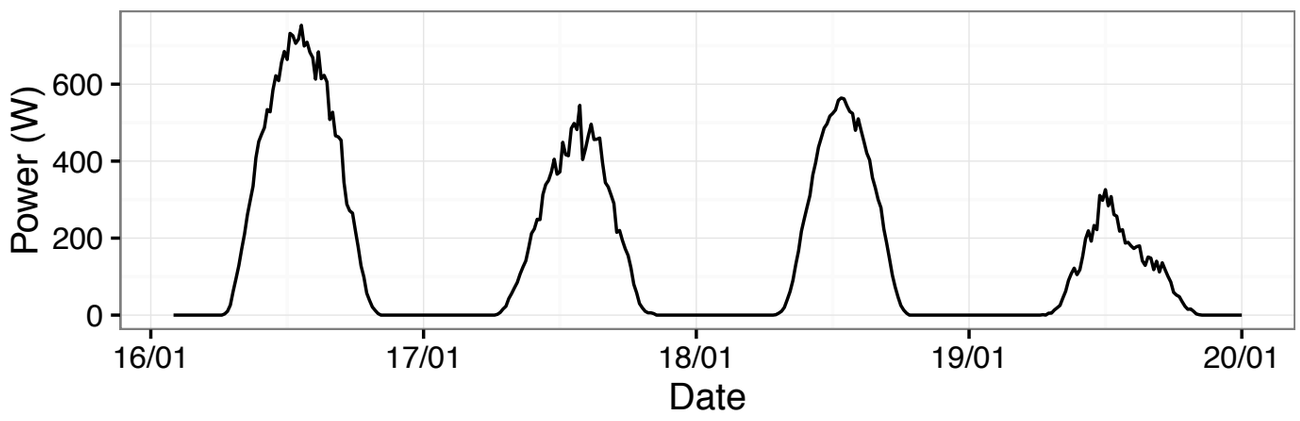
2013 — 2016

let existing and new data centres become energy adaptive

grid renewable part



sunroof PV production

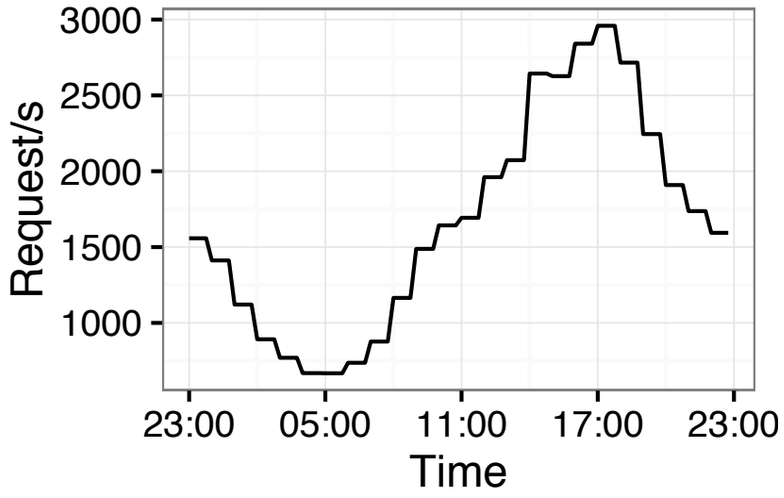


renewable energies are intermittent

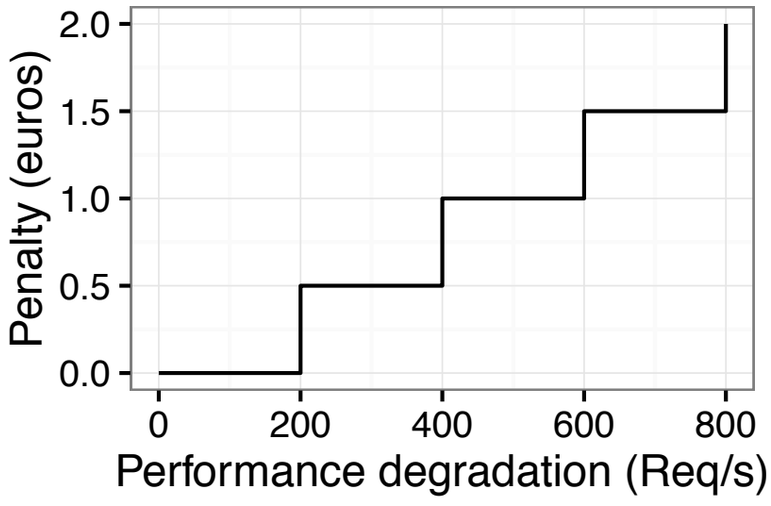
Hewlett Packard Enterprise

so are elastic and batch-oriented applications

6 to 20 moonshot cartridges



SLO

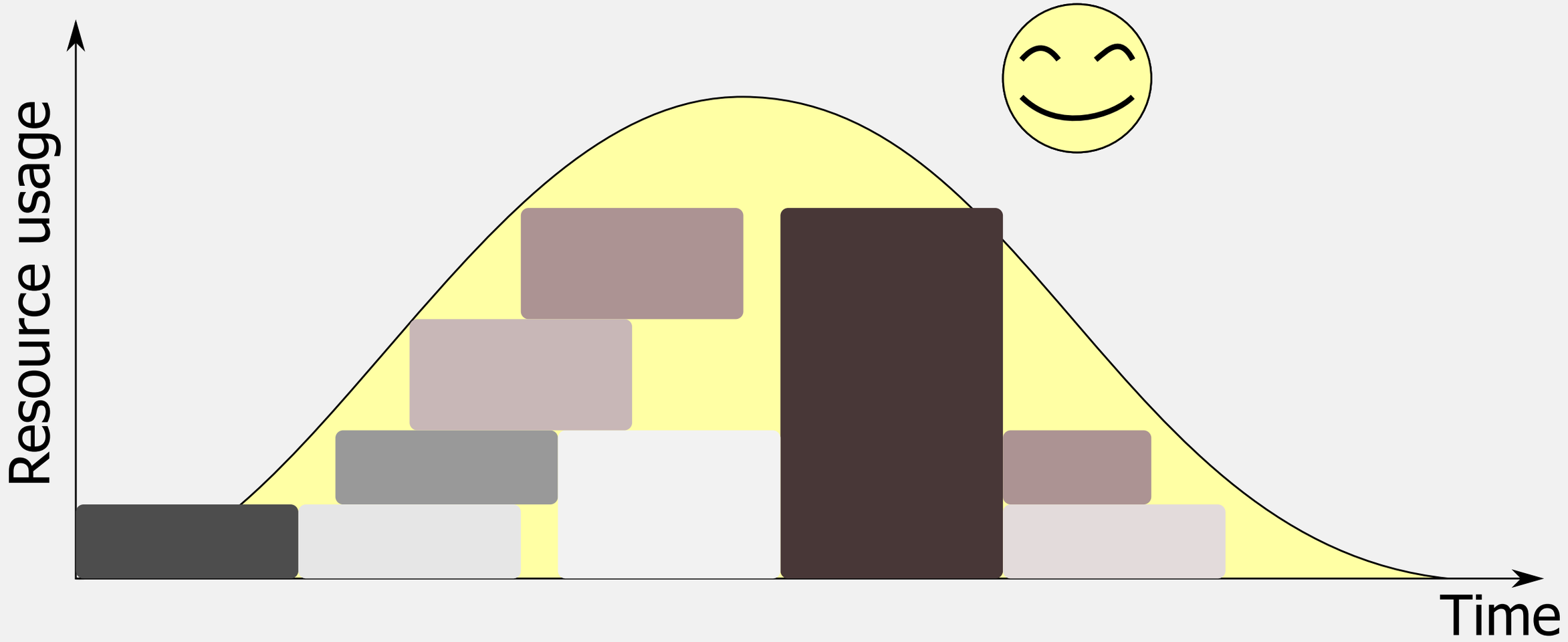


penalty model

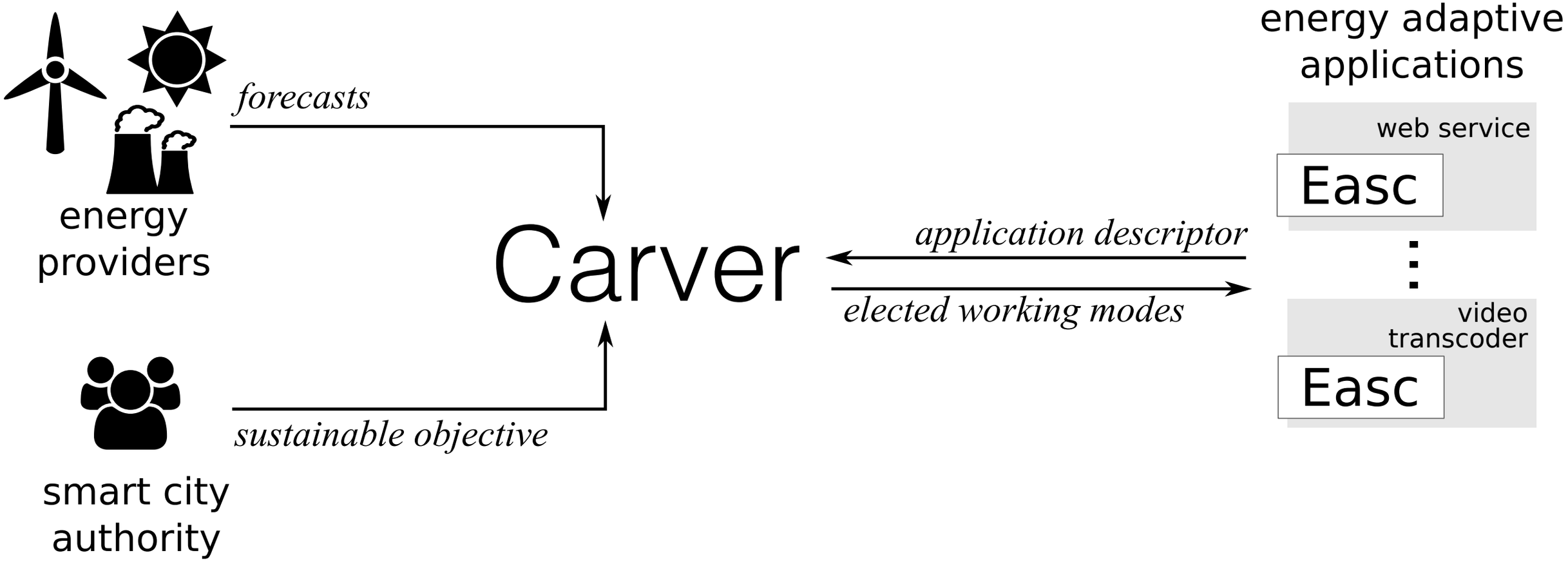
Application	Performance	Power (W)
Website	1050 – 3250 Req/s	360 – 550
G-indexing	0 – 565 kPages/h	6 – 33
E-indexing	0 – 60 kPages/h	6 – 33

align workload to renewable energies availability

DC4Cities



shape EASCs for sustainable profitability



pick WMs such as

min(penalty(SLO) + penalty(SMA) + price(E))

Energy
Adaptive
Software
Components

attached to an application

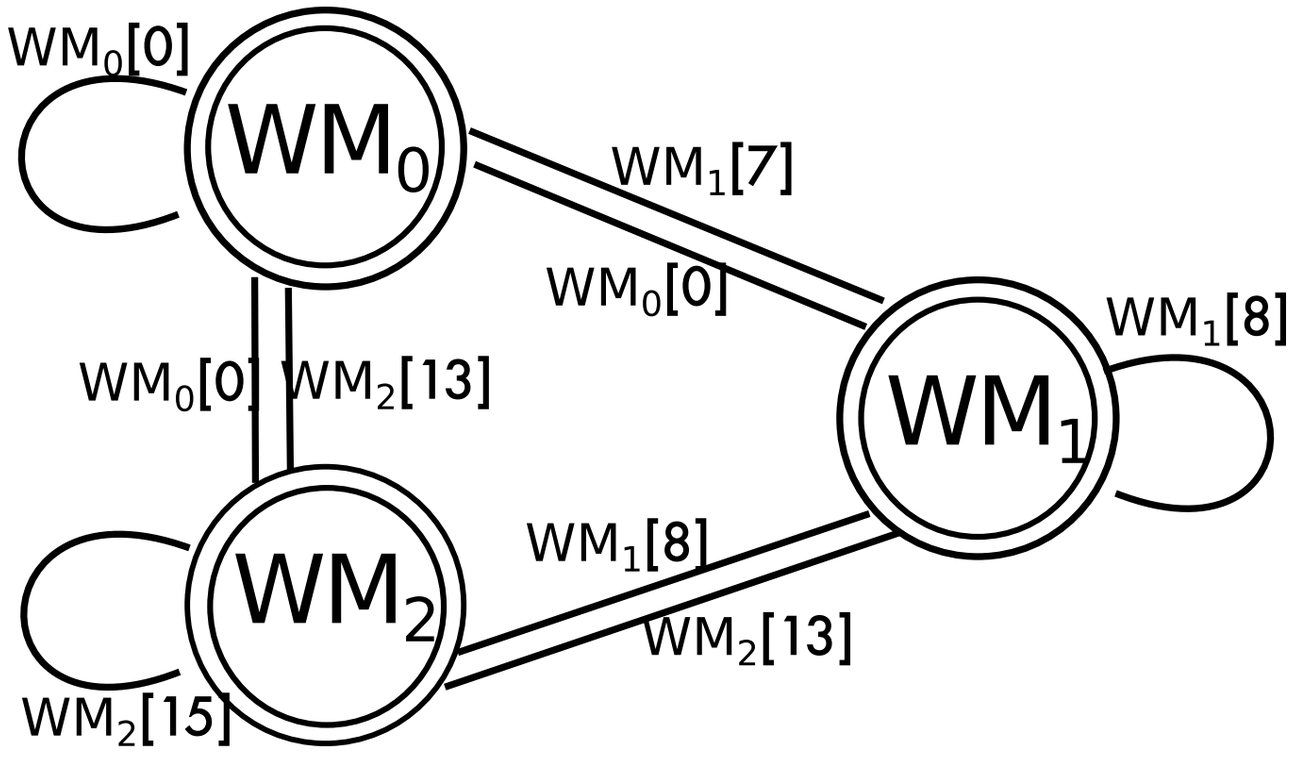
exhibit

- working modes
- SLO (cumulative or instant)
- actuators

(see UCC'15 paper)

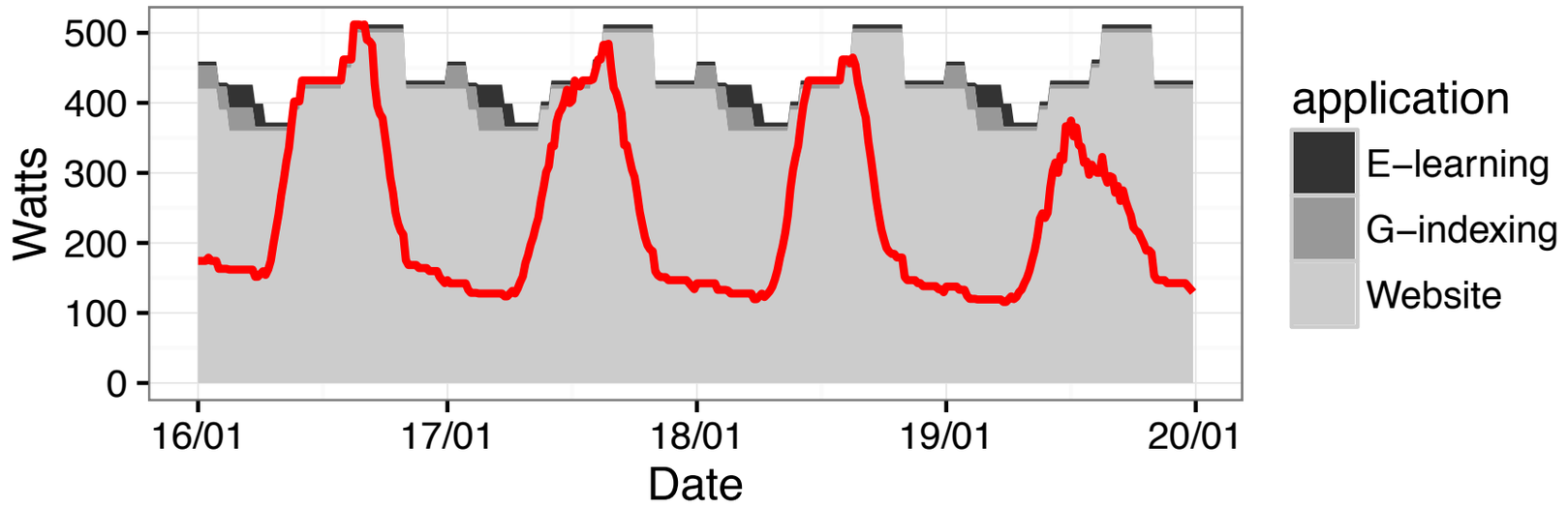
```
- name: pageIndexing
  businessUnit: kPage
  SLO:
    - timeFrom: 00:00:00
      timeTo: 24:00:00
      cumulativeObjective: !amount '200 kPage'
      basePrice: !amount '100 EUR'
      priceModifiers:
      - threshold: !amount '200 kPage'
        penalty: !amount '0 EUR/kPage'
      - threshold: !amount '100 kPage'
        penalty: !amount '-1 EUR/kPage'
      - threshold: !amount '0 kPage'
        penalty: !amount '-100 EUR'
  workingModes:
    - name: WM0
      actuator: bin/run.sh WM0
      performance: !amount '0 kPage/h'
      power: !amount '6 W'
      transitions:
        - target: WM1
          performanceCost: !amount '1 kPage'
        - target: WM2
          performanceCost: !amount '2 kPage'
- name: WM1
  actuator: bin/run.sh WM1
  performance: !amount '32 kPage/h'
  power: !amount '27 W'
  transitions:
    - target: WM2
      performanceCost: !amount '2 kPage'
- name: WM2
  actuator: bin/run.sh WM2
  performance: !amount '60 kPage/h'
  power: !amount '33 W'
```

An automaton for each EASC model the behavior,

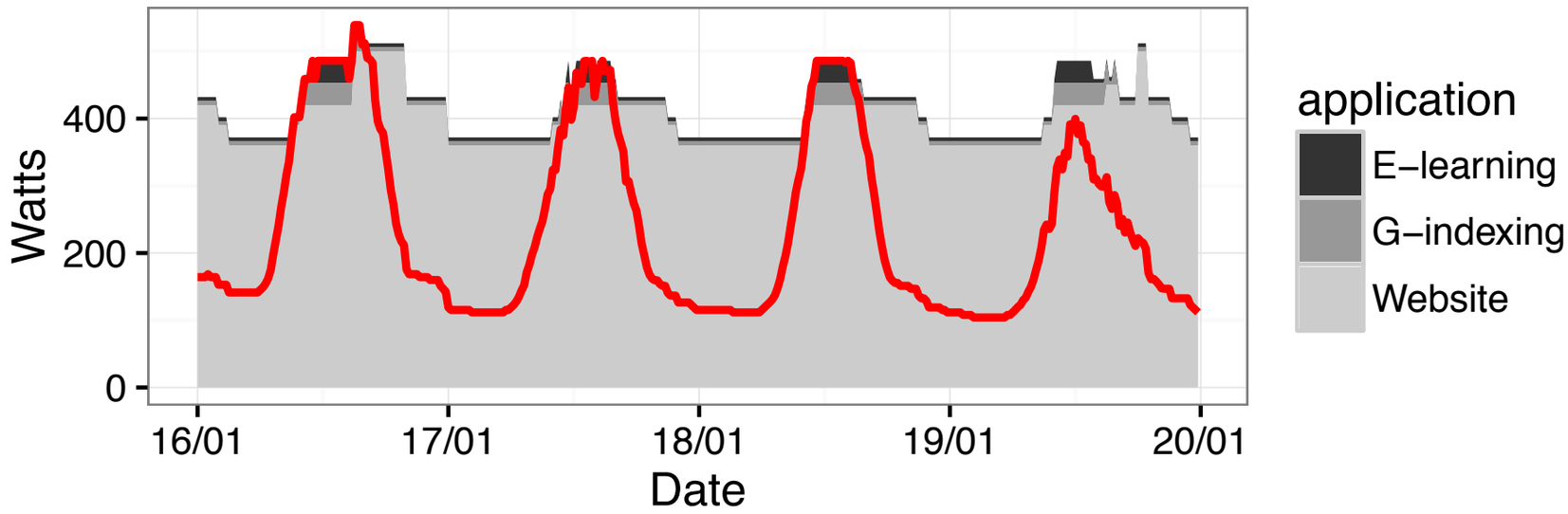


+ penalty functions for the SMA, the SLA

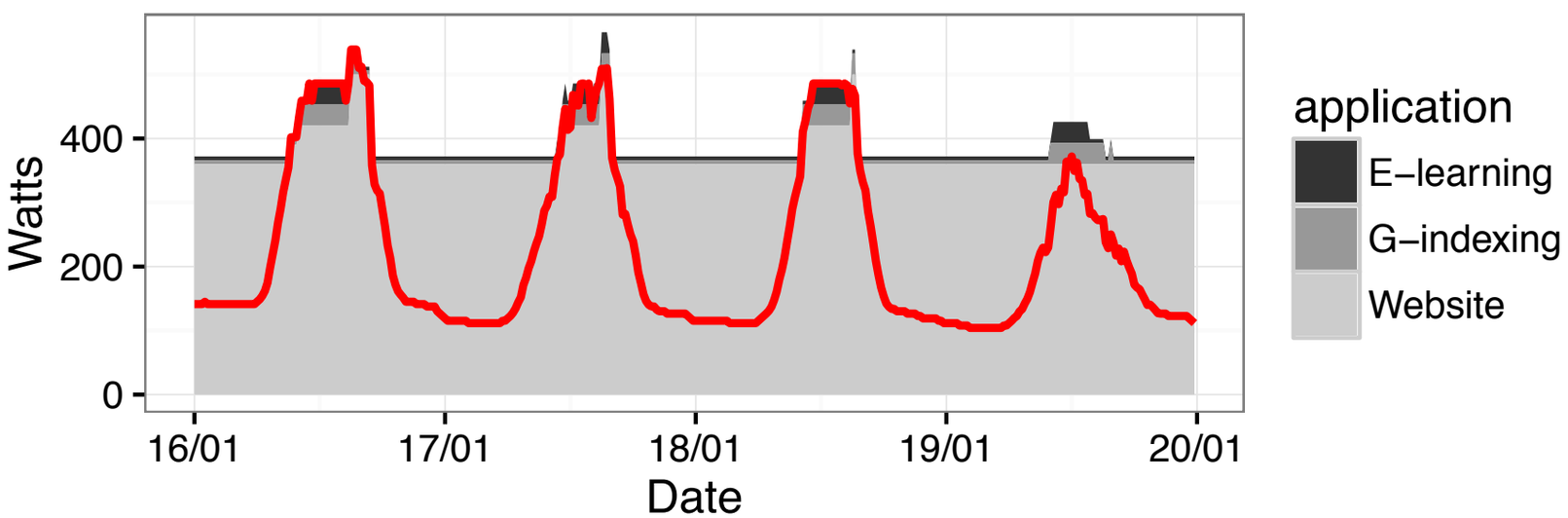
baseline
(satisfy perf)



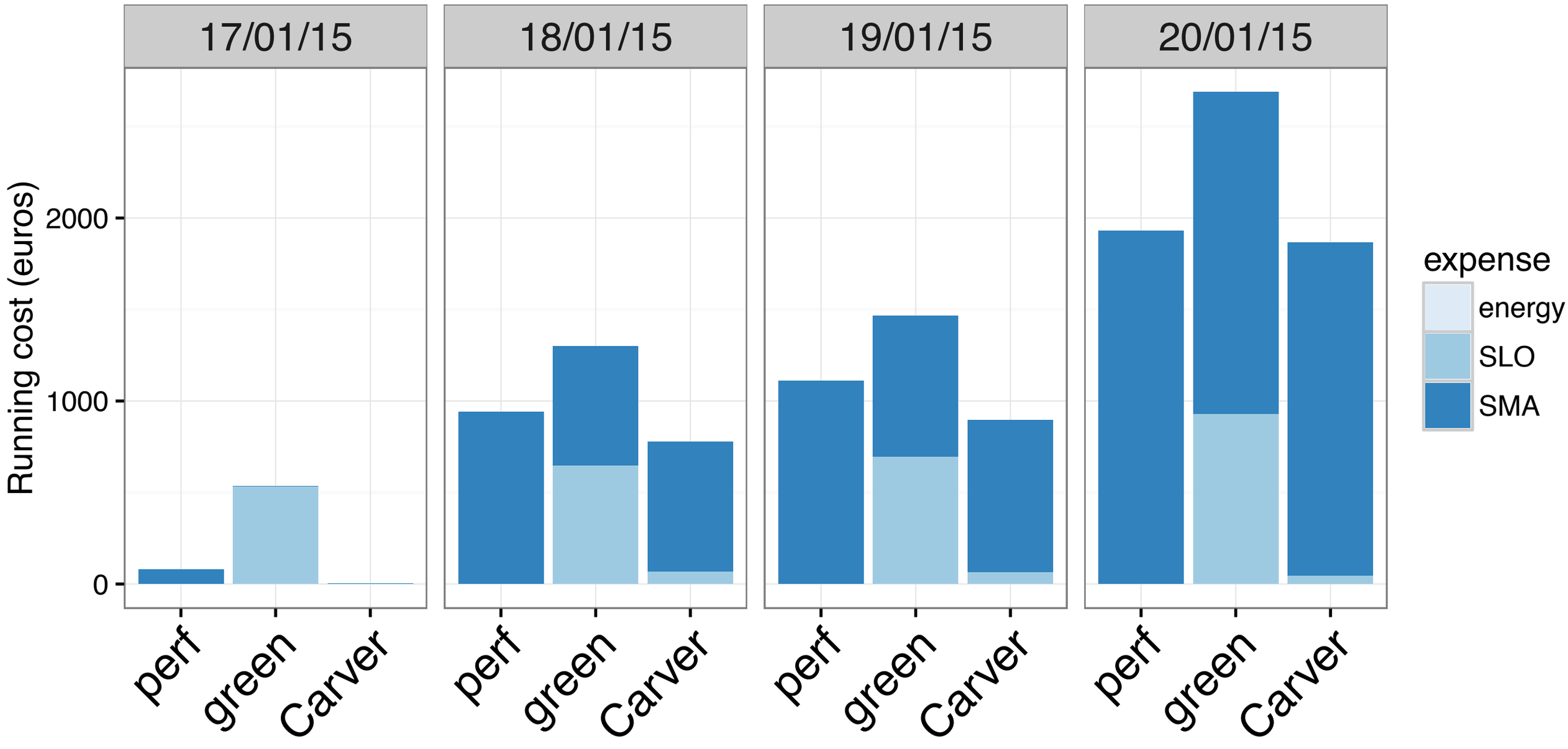
carver



“green”
(max renewable)



Resulting running costs



RECAP

no holy grail

master the problem