Cloud computing

From the resource infinity paradigm to the fluctuation paradigm

Hélène Coullon

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Source of inspiration

“Antidote to the cult of performance. Robustness from nature.”

— Olivier Hamant, 2024

Outline

1. Cloud computing and resilience

1.1 Why this topic?

Societies rely on digital infrastructures

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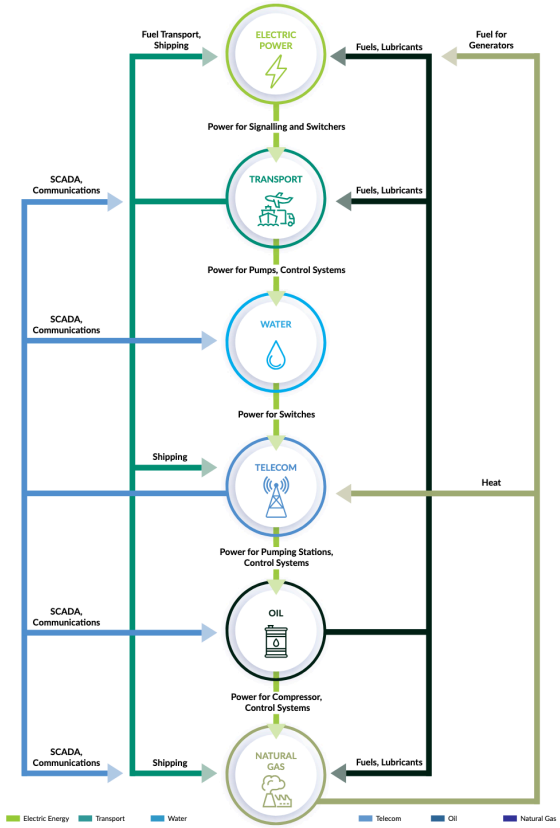
Dependencies between critical infrastructures



Source: National Strategy on the Resilience of Critical Entities 2026-2029

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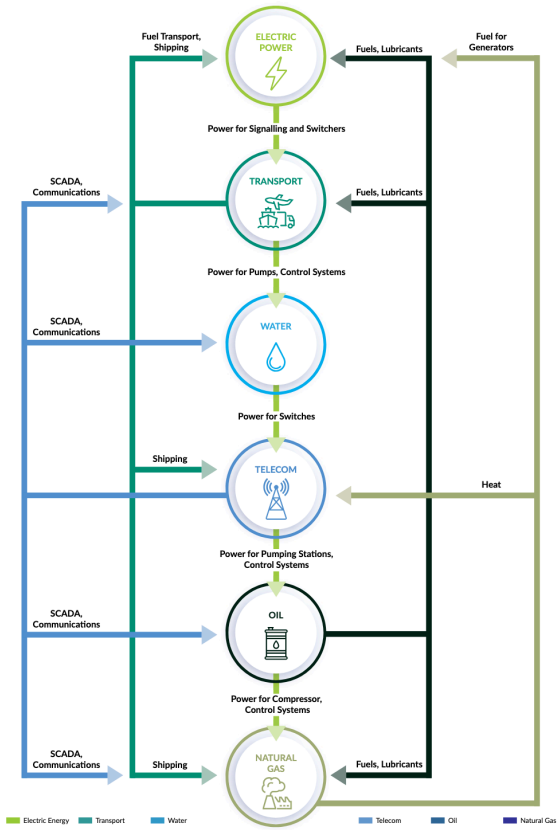

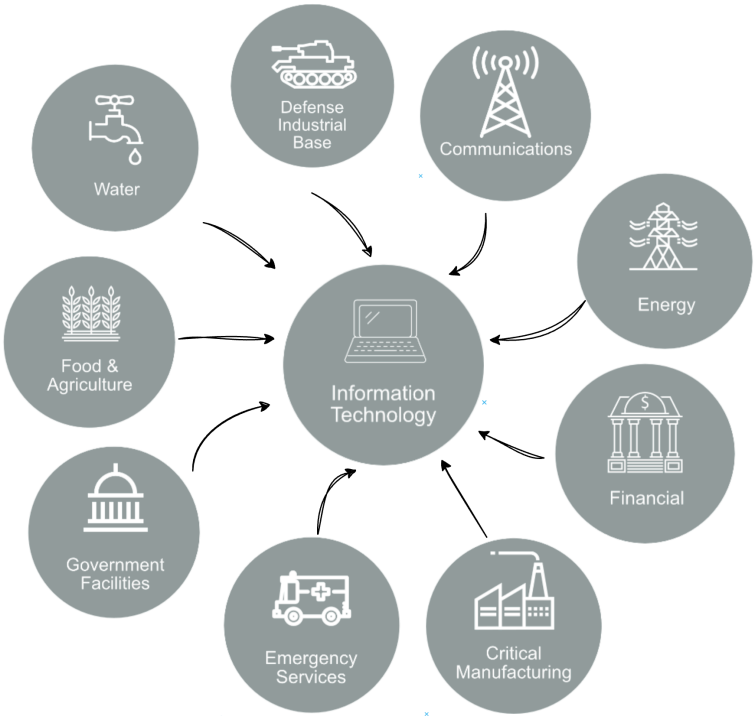

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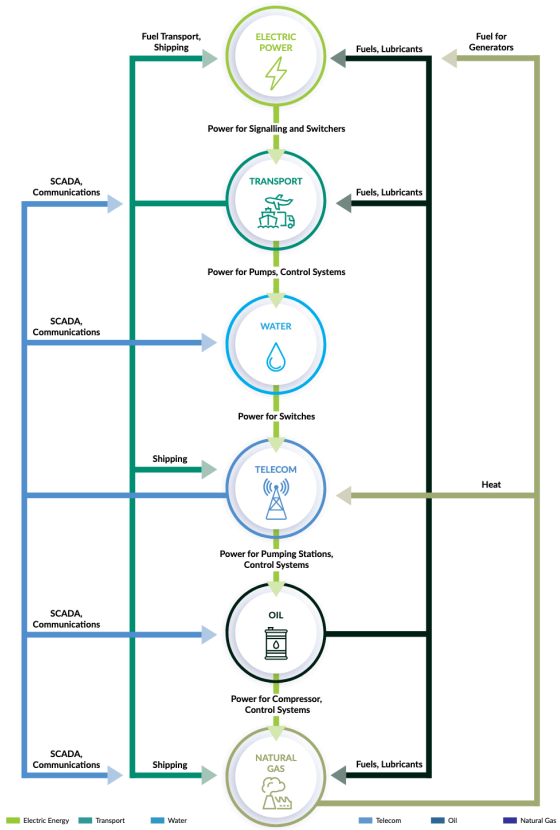

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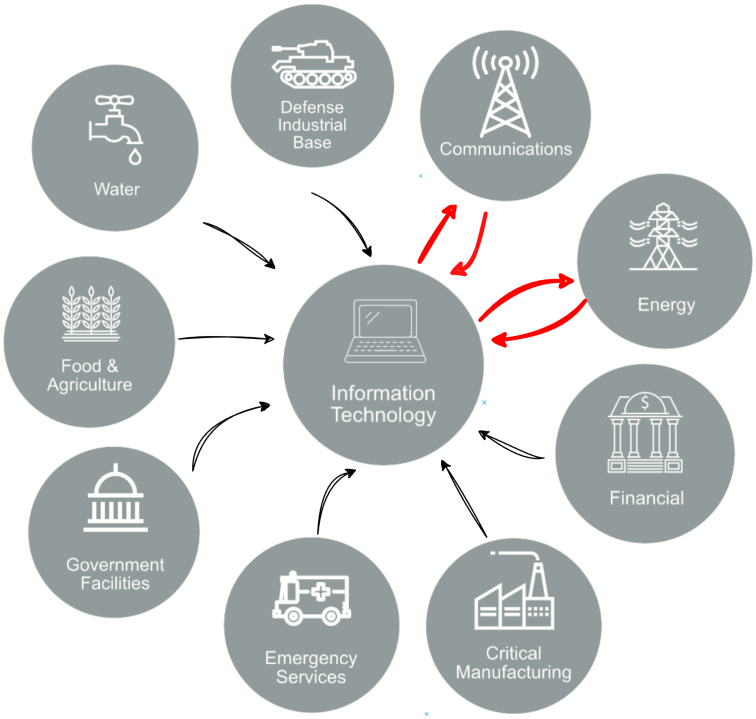
⚠ Loops



1.2 Utility computing and cloud

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"Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction."

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Cloud computing is more a private utility...

1.3 Ground computing

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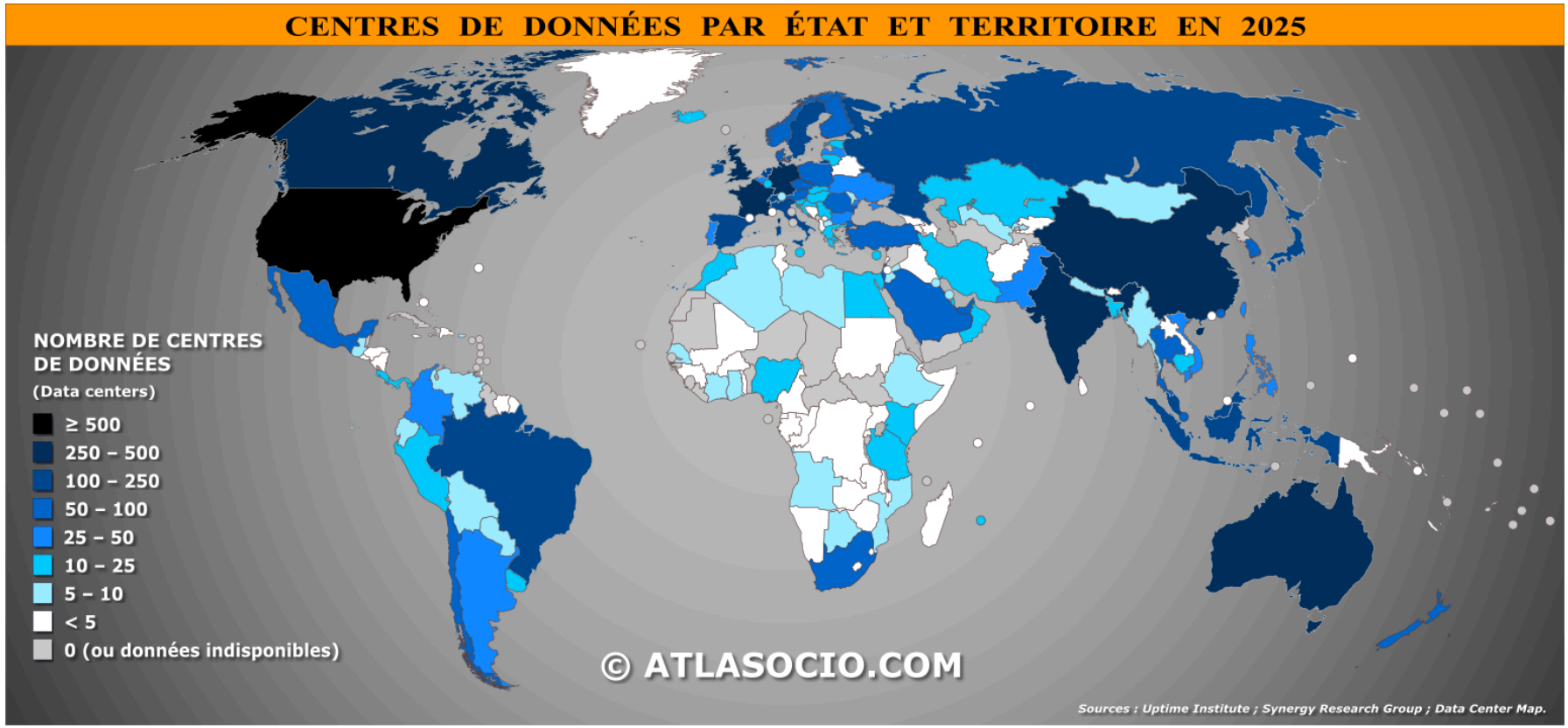

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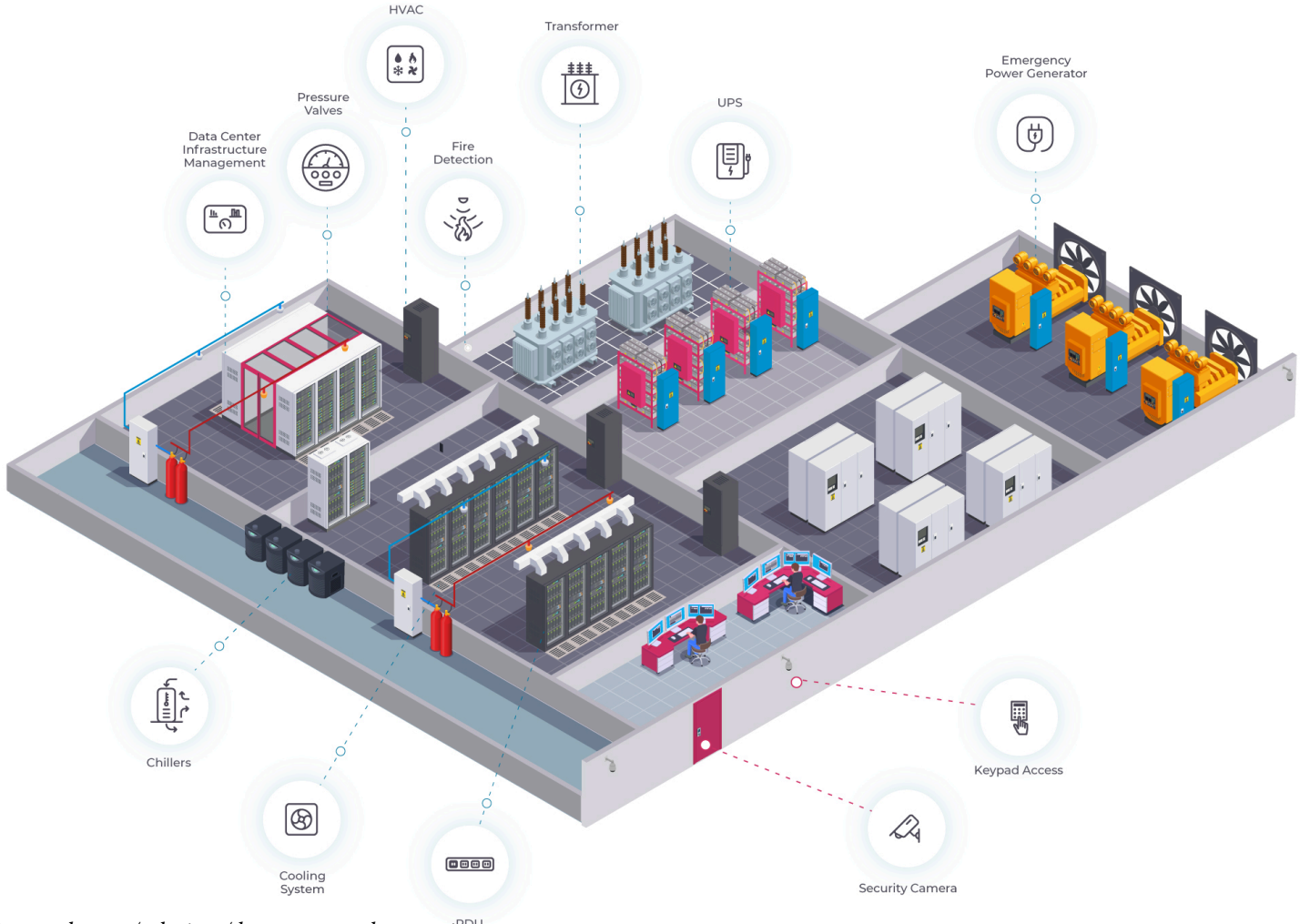

Source: https://www.nozominetworks.com/solutions/data-center-cybersecurity

1.4 Materiality

Source: https://blogs.microsoft.com/blog/2025/09/18/inside-the-worlds-most-powerful-ai-datacenter/
Microsoft's new AI datacenter campus in Mt Pleasant, Wisconsin, 2025

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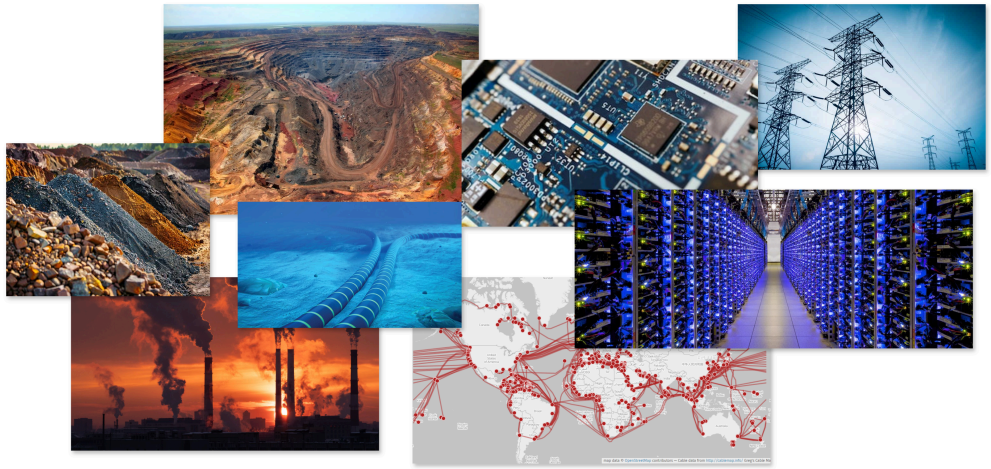


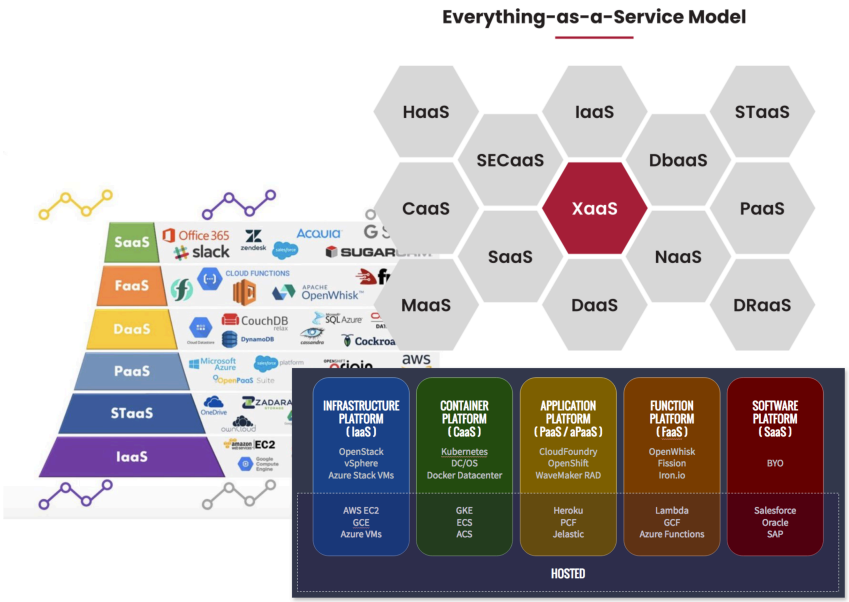
Important ecological impacts...

- ICT part in the global carbon impact: 2.1 to 3.9% in 2021 (+6% to 10% /year)
- ICT part in the electricity consumption of France: 11% in 2020 (52 TWh) (2050, +79%)
  - 65 TWh in 2020 including abroad data centers

...but also numerous external dependencies inducing fragilities!

Source: Keynote of Anne-Cécile Orgerie at INFRASTRUCTURE 2025

1.5 What about Software?



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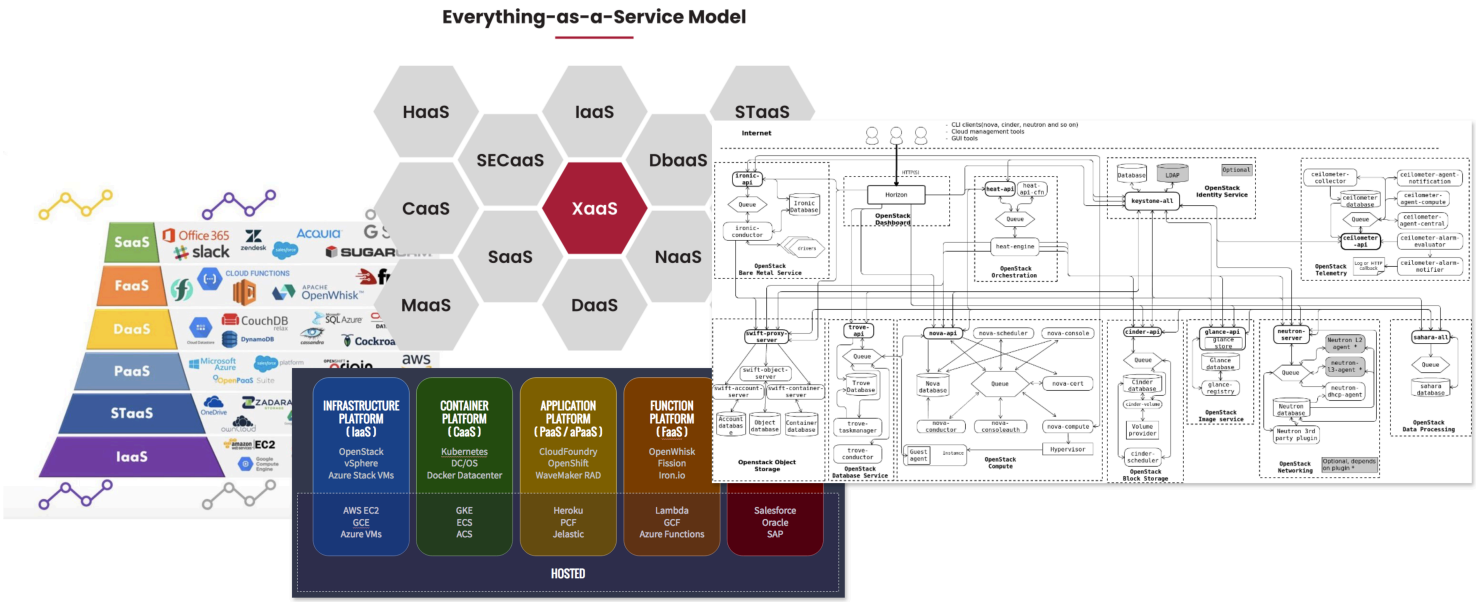

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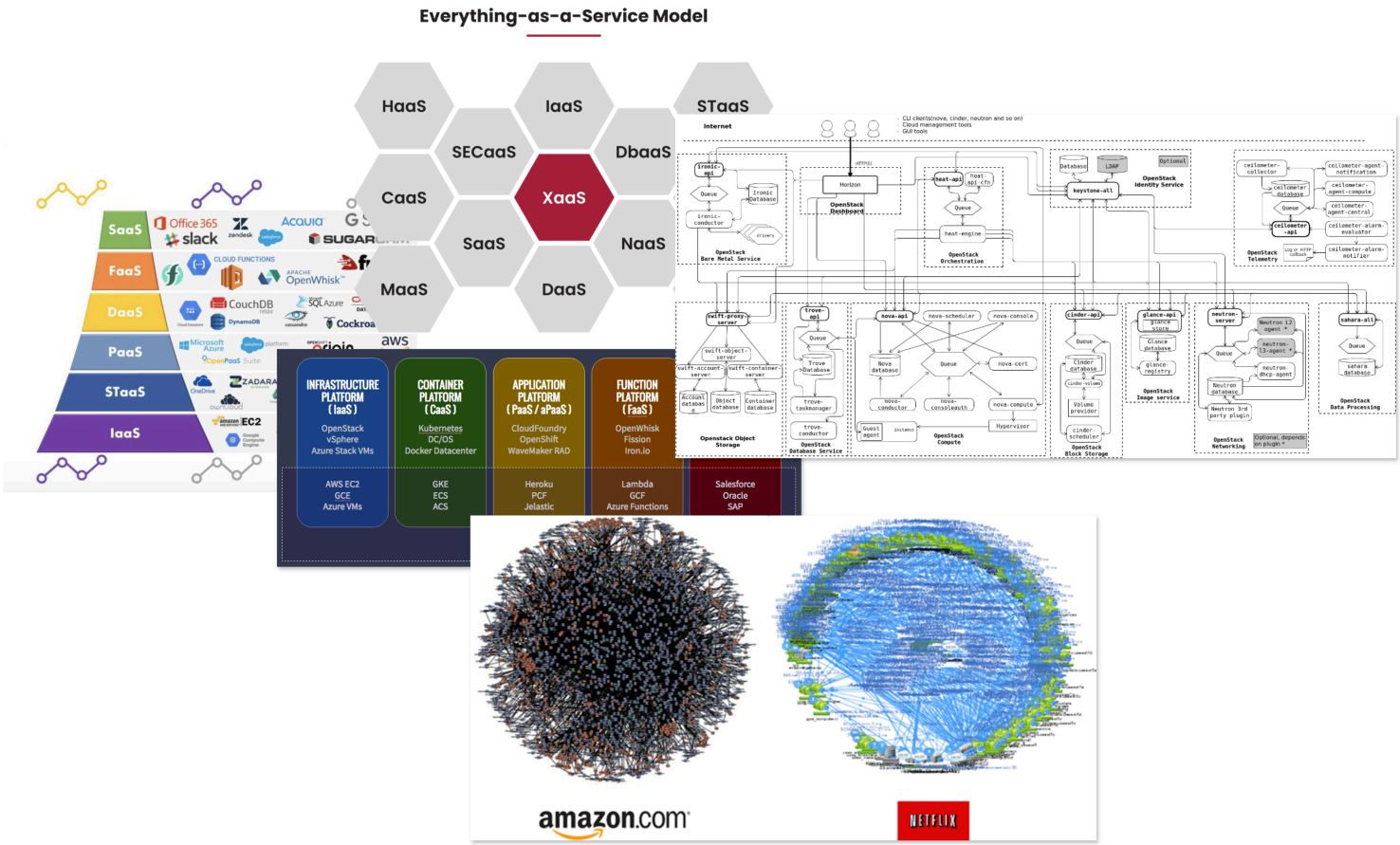

⇨ **Huge Graph of interdependent internal and external services**

1.6 Fragility

Complex evolving Systems with many dependencies

⇨ **Internal and worldwide cascading outages**

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⇨ **Internal and worldwide cascading outages**

1. Network config *2. Undersea cable cuts* *3. Incompatible metadata in CDN*	*Bad automated update quota check system*	*Race condition in Amazon's DynamoDB's DNS*	*Larger than expected file replication*
			
Jan. 2025, 50h Sept. 2025 Oct. 2025, , 10h	June 2025, 3h	Oct. 2025, 15h	Nov. 2025, 8h

1.7 Resilience

Resilience

Resilience is used as an integrative concept that encompasses system robustness, survivability, recovery, and adaptability

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SODIs are generally **resilient** (i.e., able to recover after incidents)

⇨ stability/survivability of control services and critical dependencies

- high replication and redundancy
- inifinte resources (computing, energy, water, batteries, etc.)
- stability of external services

2. Fluctuation paradigm

2.1 Polycrises

Amongst others

- climate change
- natural resource scarcity
- geopolitical instability

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Dependability, fault tolerance, reliability

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Fluctuation

An **irregular** rising and falling in number or amount

2.2 The fluctuation paradigm

- Electrical fluctuations
- Fluctuations in access to water
- Temperature fluctuations
- Fluctuations on hardware supply
- Fluctuation in network quality or connectivity
- Fluctuations to access data, software, services, applications
- etc.

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New Texas law allows ERCOT to disconnect data centers during peak events

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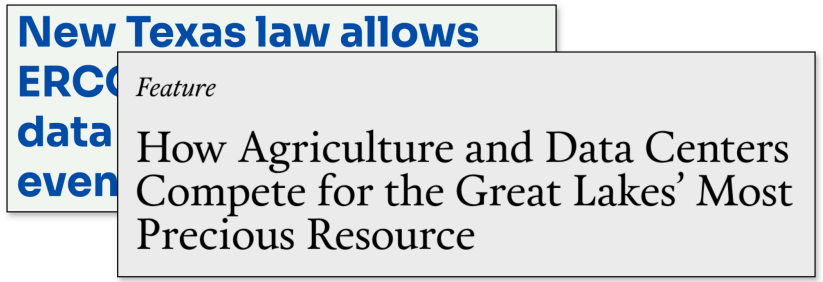

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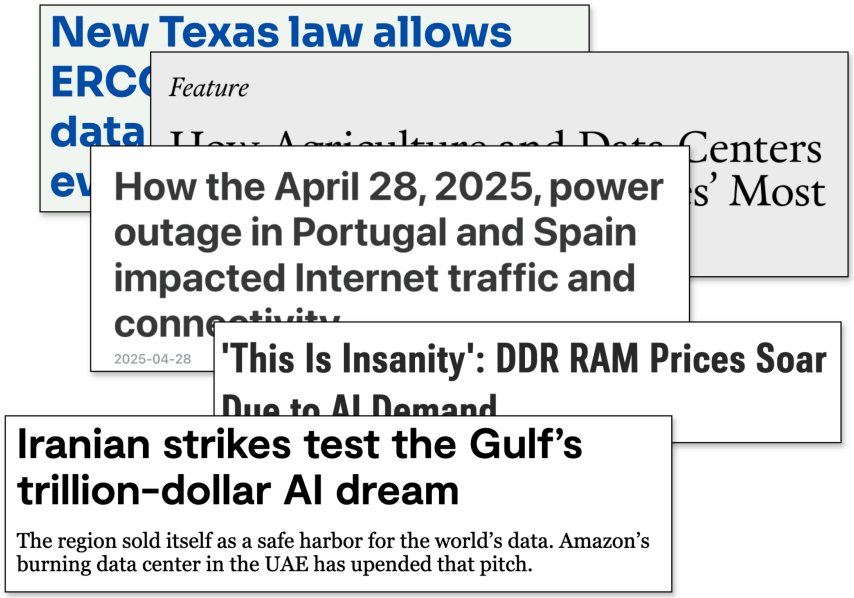

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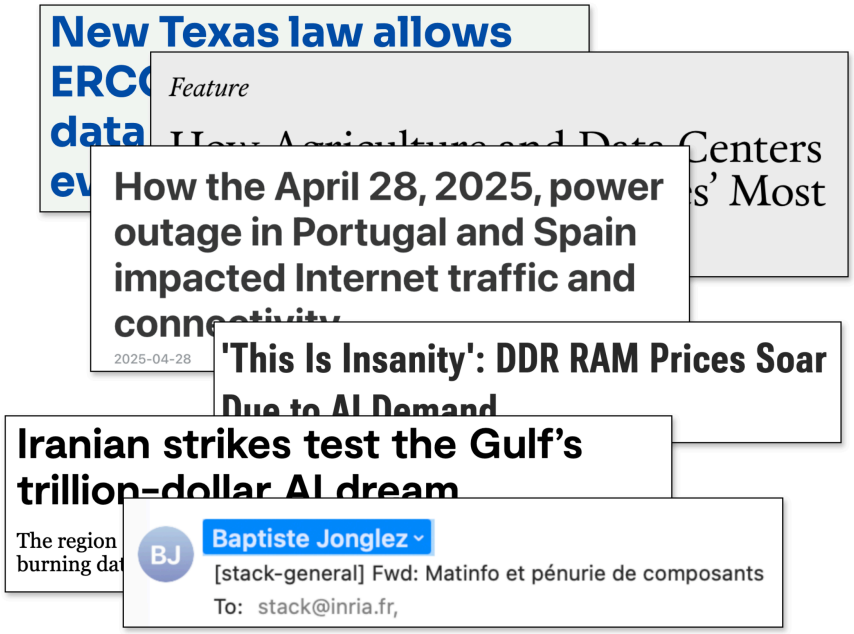

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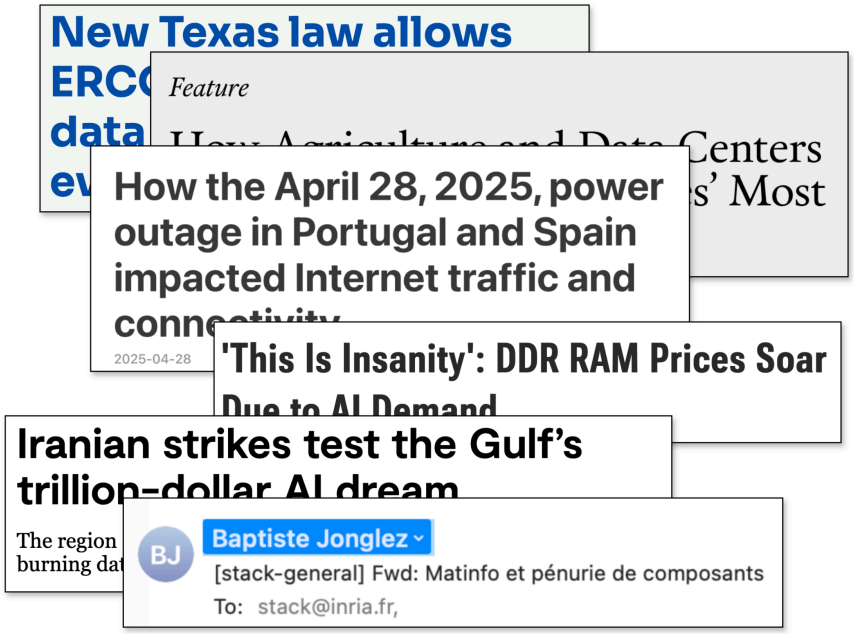


"Modern Internet services are composed of hundreds of interdependent systems spanning dozens of geo-distributed data centers. At this scale, seemingly rare natural disasters, such as hurricanes blowing down power lines and flooding, occur regularly"

— Facebook researchers, OSDI 2018 [1]

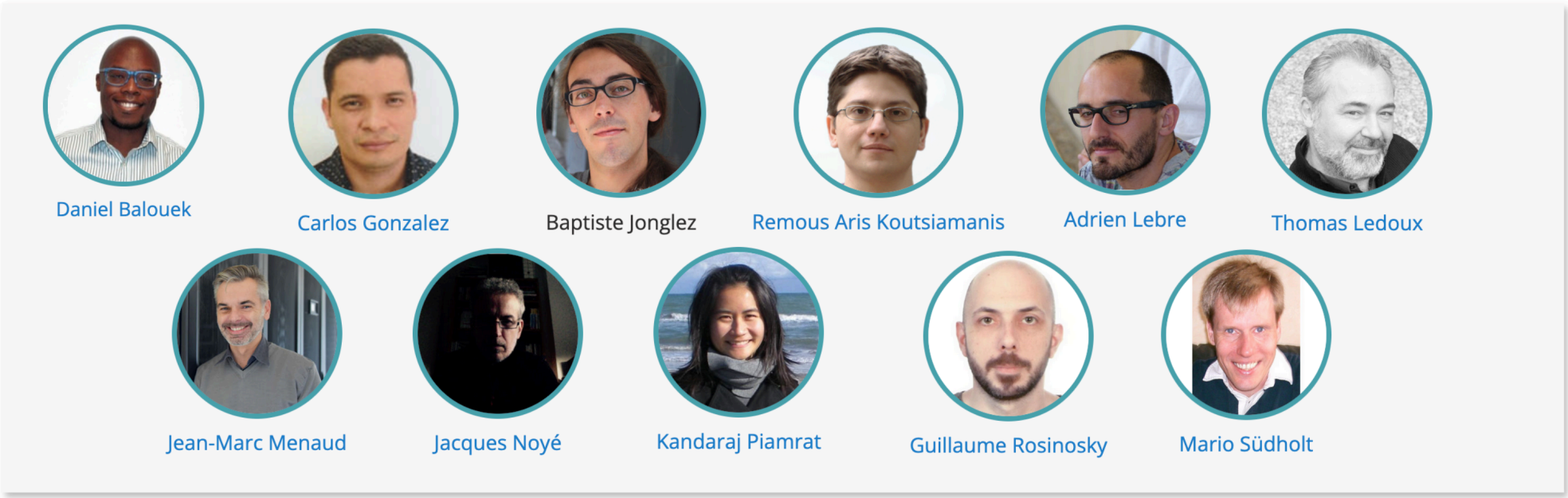
3. RIFT

3.1 New Inria team - RIFT

Resilience of digital Infrastructures to resource FlucTuations

⚠ Still under creation

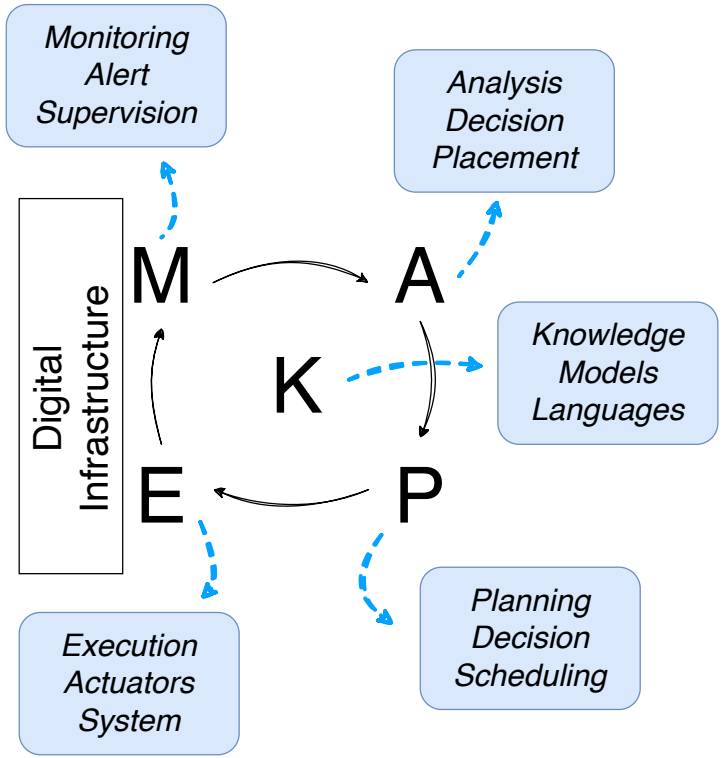
⇨ Following the current STACK research group of Adrien Lebre



3.2 Scope of RIFT

(Resilient) Software systems for SODI management.

Examples: OpenStack, Kubernetes, OpenWISP, OpenFaaS, OpenFL, OpenDaylight etc.



3.3 Research program

- **Axis 1**: Considering limitations and degradations
  - Conectivity, energy, hardware

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  - urgency, high frequency, long-term permanent
- **Axis 3**: Handling the spatial scales of fluctuations
  - geography and territoriality, sovereignty
- **Axis 4**: Evaluating resiliency
  - Metrics, benchmarks, resilience-oriented platforms

4. Focus on reconfigurations

4.1 Dynamic reconfigurations

- Dynamic reconfiguration originates from CBSE [2]
  - models able to dynamically change the assembly of components
  - focus on PE-K of MAPE-K
- Metrics: minimize downtime, mean time to recovery
- Formalization and verification of reconfigurations

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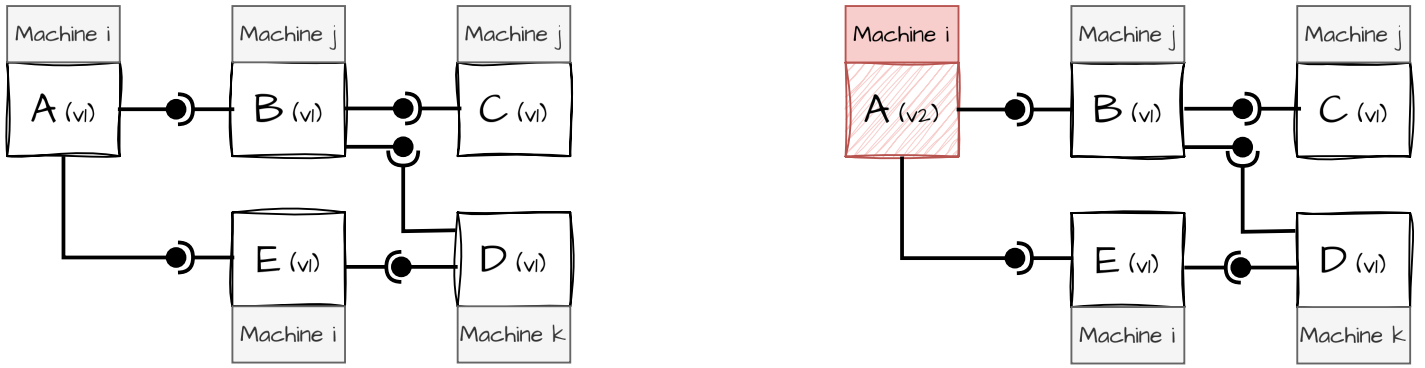
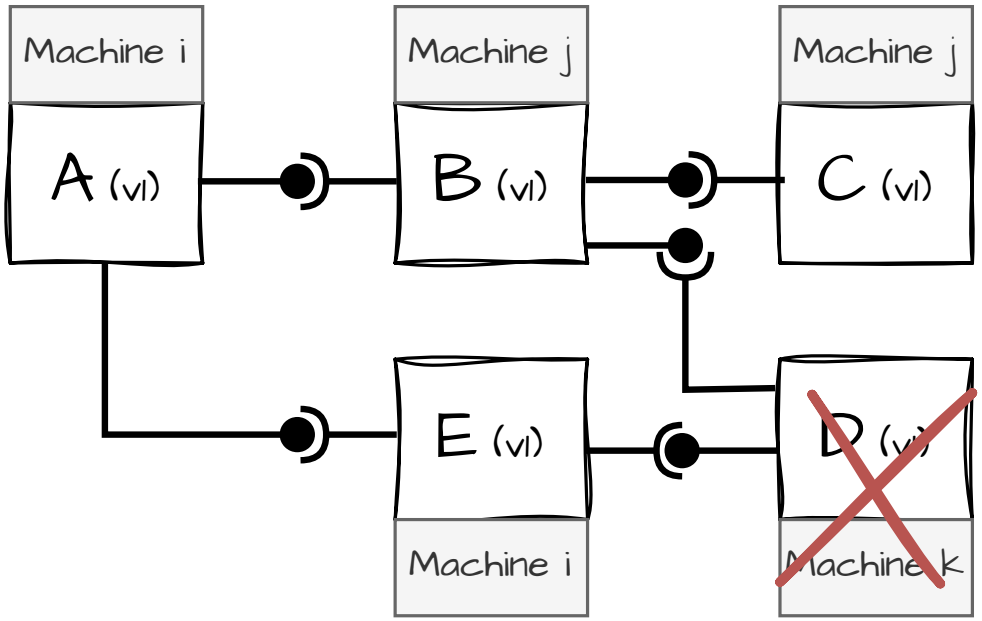
⇨ **Concrete example: update component A in the assembly**



4.2 Concrete examples

Version 1



delete(D)

4.2 Concrete examples

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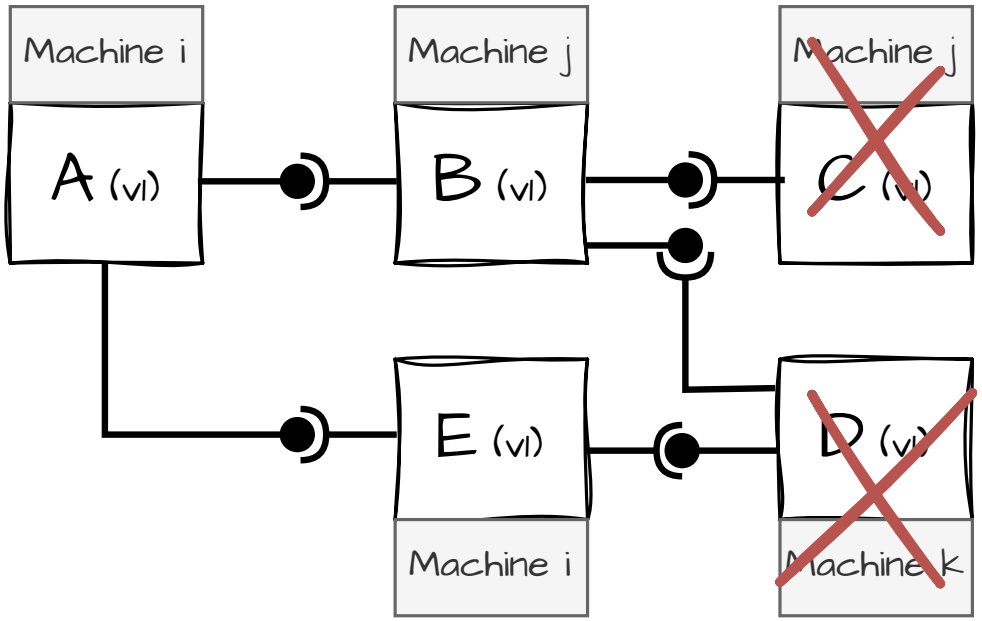

delete(D); delete(C)

4.2 Concrete examples

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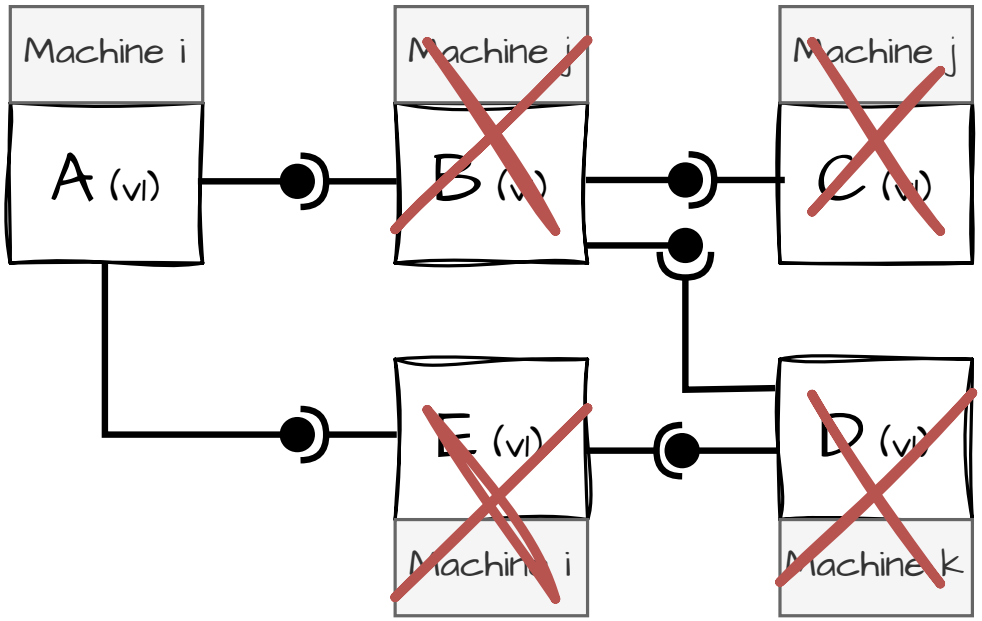

delete(D); delete(C); delete(E); delete(B)

4.2 Concrete examples

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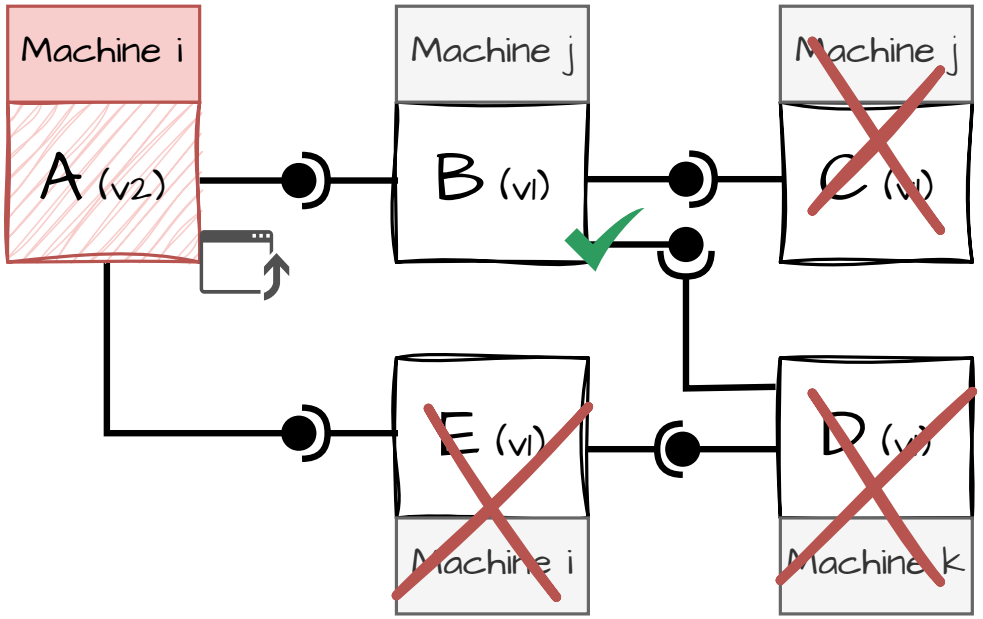

delete(D); delete(C); delete(E); delete(B); update(A); start(B)

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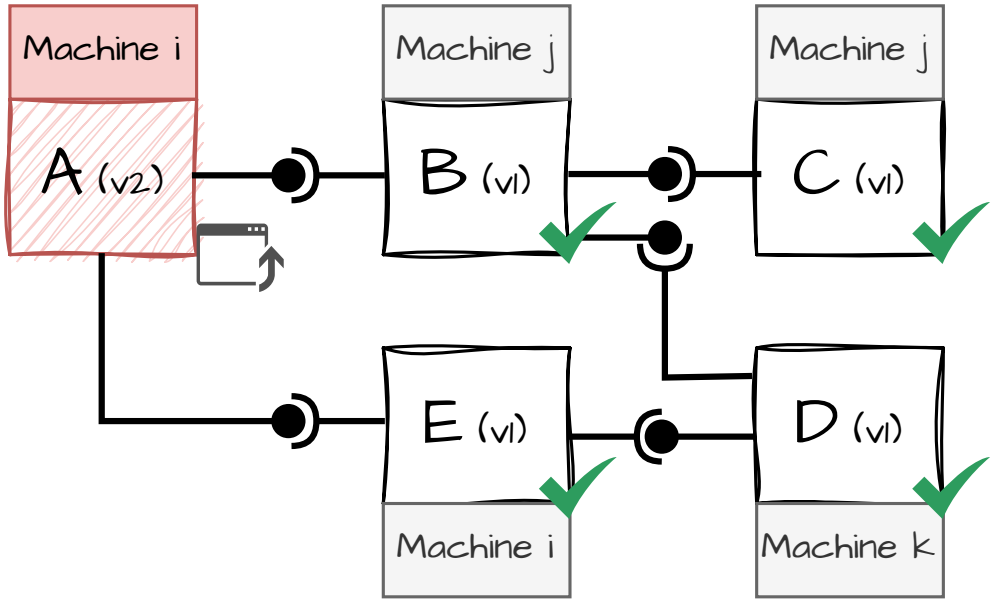
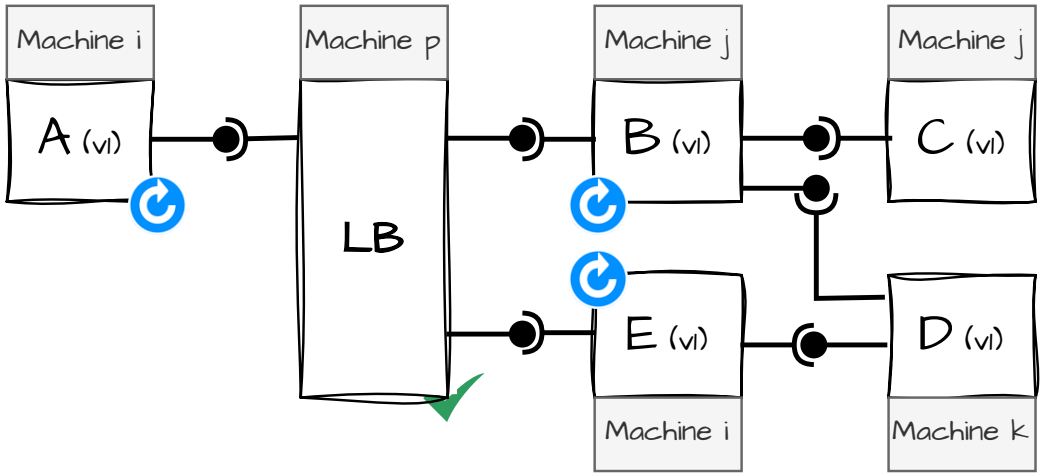


delete(D); delete(C); delete(E); delete(B); update(A); start(B); start(E), start(C); start(D)

4.3 Concrete examples

Version 2



start(LB); restart(B); restart(A); restart(E)

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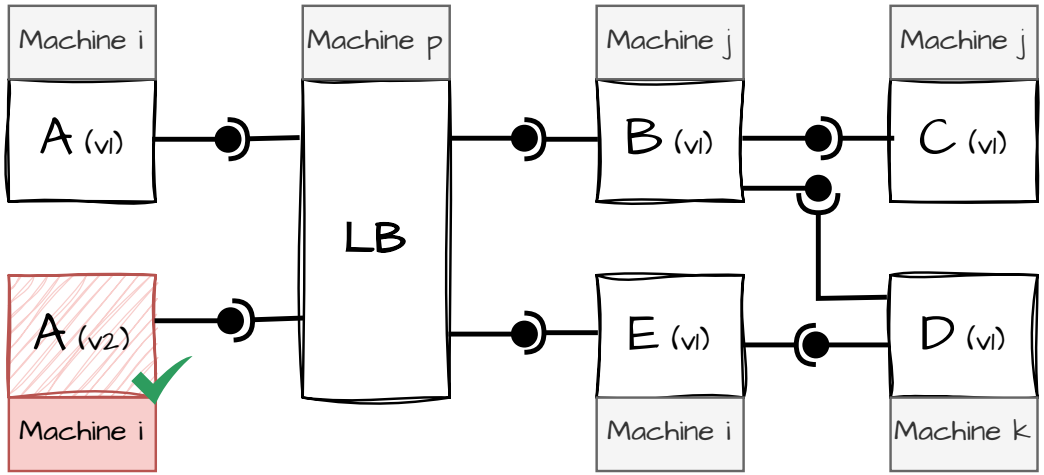

start(LB); restart(B); restart(A(v1)); restart(E); start(A(v2))

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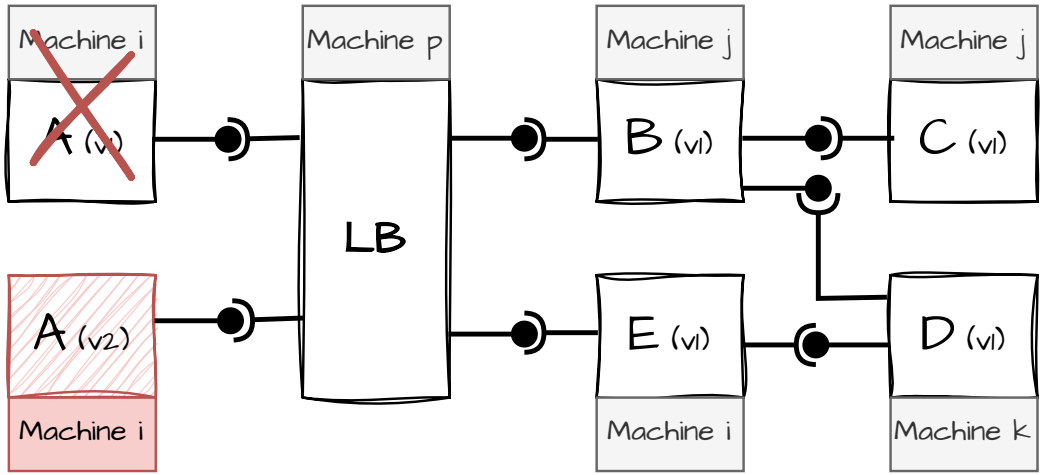

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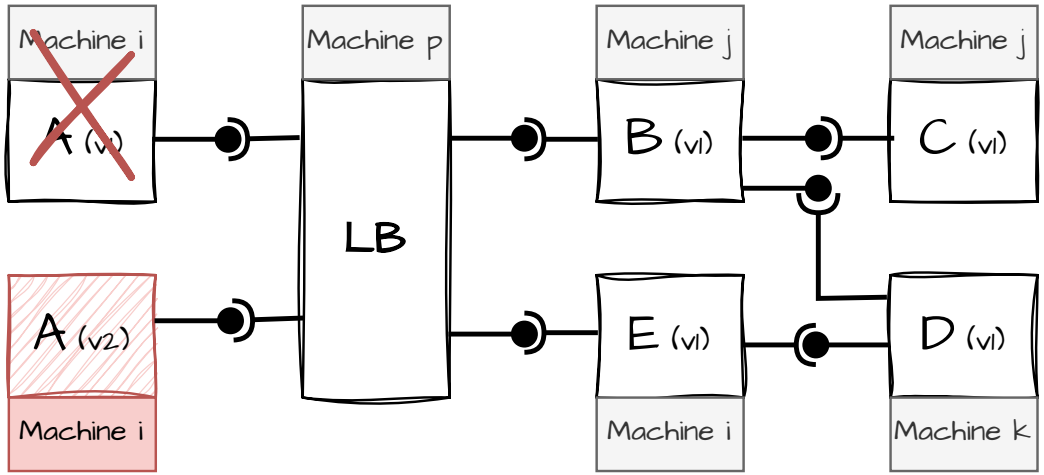


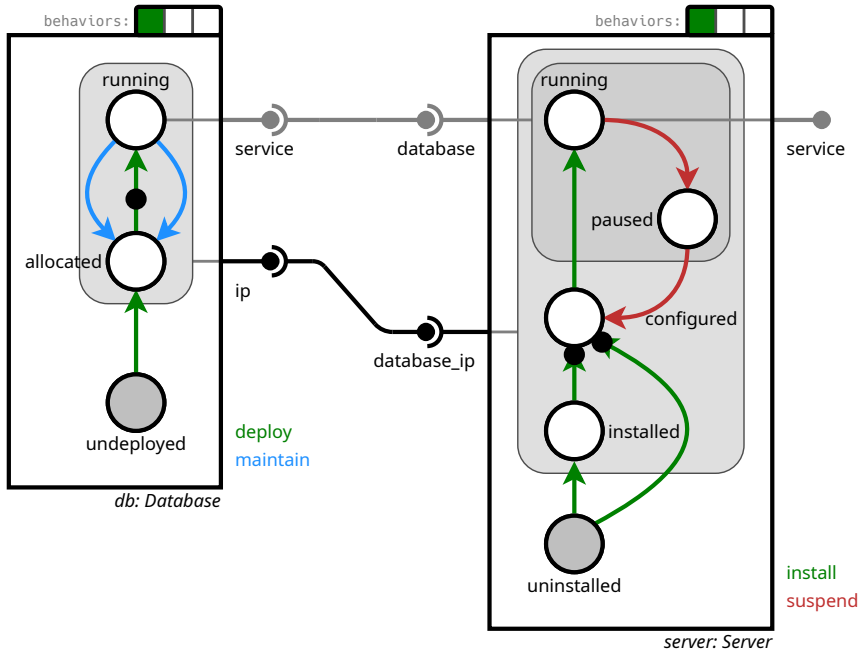
start(LB); restart(B); restart(A(v1)); restart(E); start(A(v2)); delete(A(v1))

⇨ ***Much more complex lifecycle actions than version 1***

4.4 Programmable lifecycle

Safe programmable lifecycle management with Concerto [3]

```python
add(server: Server)
add(db: Database)
con(server.database_ip,db.ip)
con(server.database,db.service)
pushB(server,install)
pushB(db,deploy)
wait(server)
```



- Automatic and safe coordination of programmable lifecycles
- Reconfiguration language with 6 generic instructions

4.5 Infrastructure-as-Code

Infrastructure-as-Code (IaC)

- Tools to automate and manage infrastructures through codes
  - Sharable, testable, versionable, etc.
- IaC embeds reconfiguration, adaptation, and lifecycle management

How the fluctuation paradigm challenges reconfigurations and IaC?

- Reconfiguration and IaC is a way to reach a **new stable state**
  - **Safety** is required to be sure of this state and its reachability
- To reach the new state the **reconfiguration tool has to be resilient**
- If facing urgency the **reconfiguration should respect a deadline**
- etc.

5. Safe reconfigurations

5.1 Code synthesis (plan)

Safe Concerto code generation [4]

- **Inputs**: current state of the system (M) + reconfiguration goals (A)
  - set of behaviors to execute on designated components
  - constraints on the final state of ports

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Problem formulation

Find a valid (optimal) schedule of pushB and wait instructions (in Z3)

5.2 Safe IaC

Lifecycle coordination in IaC

- **CoAnsible**: Ansible extension for clear composition of roles
- ***CoTerraform**: replace too restrictive static CRUD lifecycles*
  - *Ph.D. of Simon Artus*

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Formal IaC

- **BPlan** Terraform: augmented plan with model-checking (Maude)
- **For-CoaLa ANR project**: formalization and proofs on Ansible [5]
  - *Ph.D. of Olivia Proust*

6. Resilient reconfigurations

6.1 Centralized reconfigurations

Either in academic reconfiguration or IaC

⇨ **solutions are centralized**

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⇨ **solutions are centralized**

- Central global state
- Central analysis/planning computation

Associated fragilities

- **Failures/disconnections**: Inconsistent state, state drifts
- **Failures/disconnections**: No local progress is possible
- **Privacy**: no shared state in cross-DevOps organization

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Exceptions:

- *Kubernetes (distributed ETCD database, individual controllers)*
- *Mjuz (decentralized Pulumi) [6]*

6.2 Ballet

Decentralized reconfigurations with programmable lifecycles

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- **Concerto-D** [7], [8]
  - A formalized collaborative Concerto (Maude)
  - Synchronizations: disconnections, ports and baheviors statuses

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  - Local CP (constraint programming) model
  - Gossip constraints propagation for models enrichment
  - Final consensus to end the collaborative process

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***Future work**: Decentralized and local-first IaC*

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Frequent fluctuations

- No stable/quiescent state
- Concurrency regime of reconfigurations

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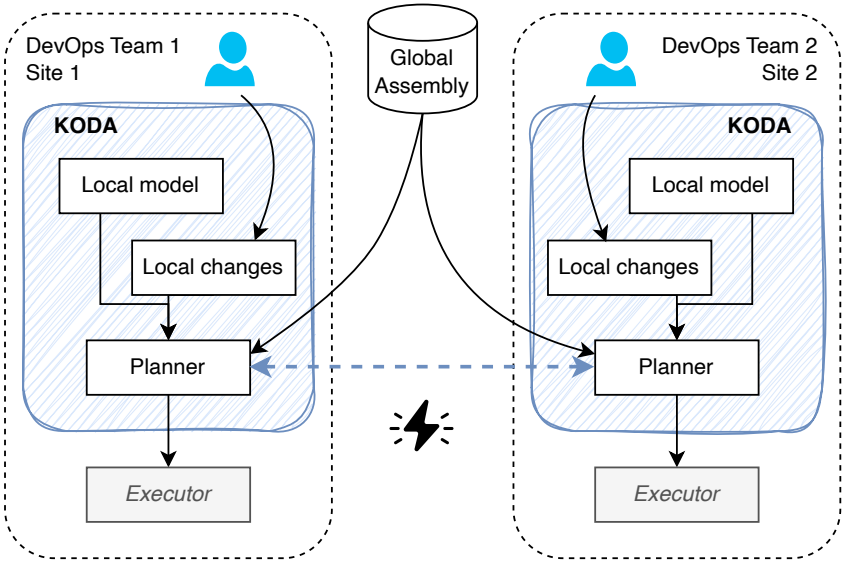
Conflict detection with Koda

- Ballet = reconfigurations one by one
- Koda = concurrent reconfigurations
  - detects conflicts
  - finds the causality of conflicts

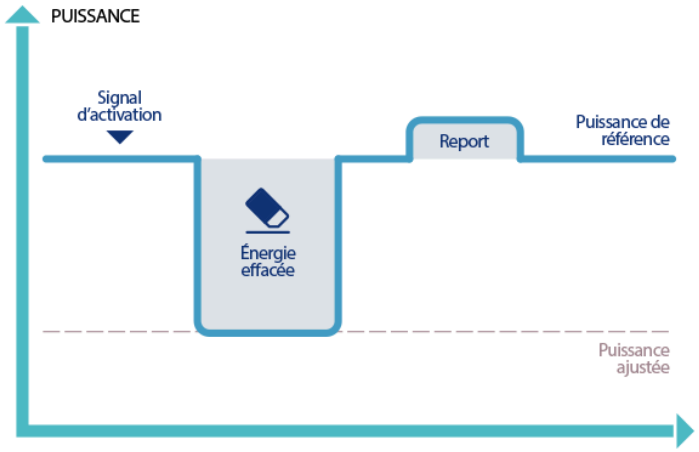


7. Timely constrained reconfigurations

7.1 Context

Deadline to reconfigure

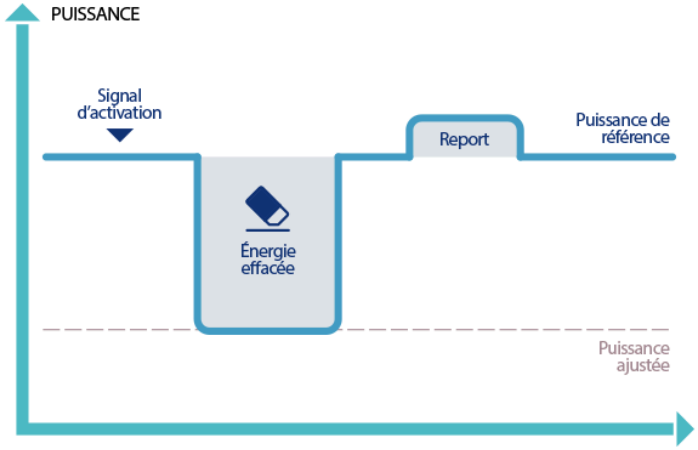
- PEPR Cloud + PEPR TASE
  - Collaboration with RTE
  - Collaboration with Ctrl-A
  - *Ph.D. of Nathan Rabier*



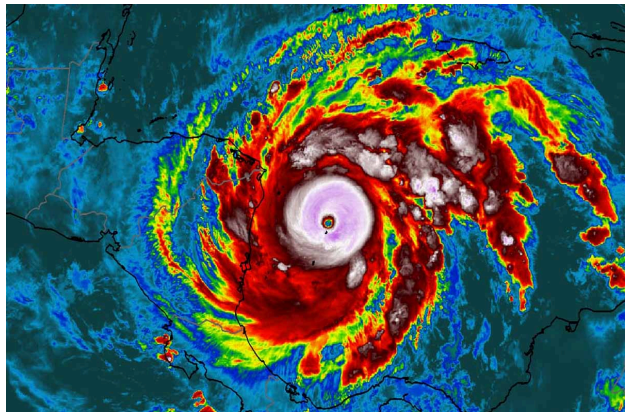
7.1 Context

Deadline to reconfigure

- PEPR Cloud + PEPR TASE
  - Collaboration with RTE
  - Collaboration with Ctrl-A
  - *Ph.D. of Nathan Rabier*



- Urgency in reconfigurations
  - Urgent computing



7.2 Challenge

⇨ **Strong deadline to adapt (MAPE)**

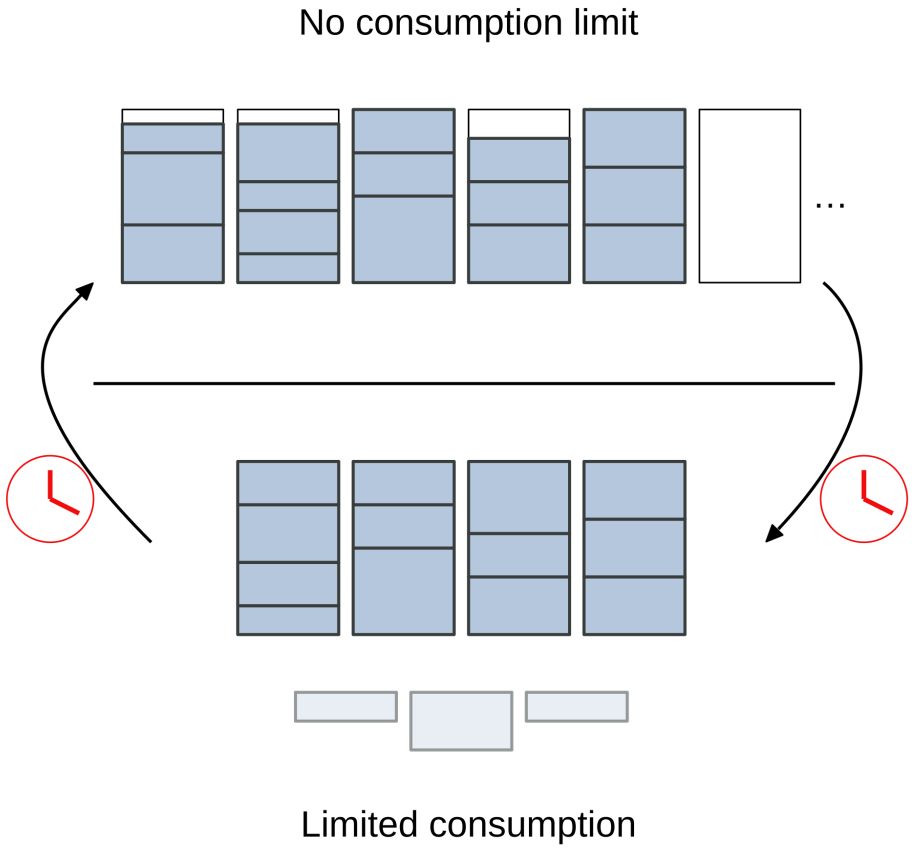
7.2 Challenge

⇨ Strong deadline to adapt (MAPE)

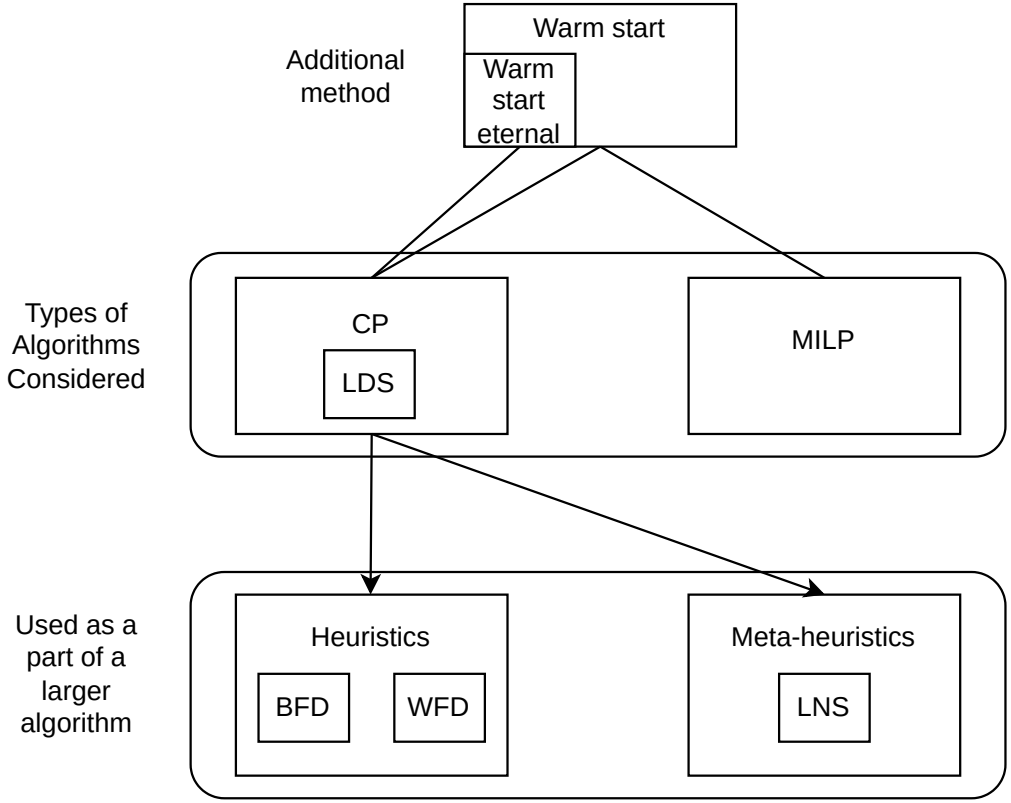
Le réseau de transport d'électricité

Switching between two configurations

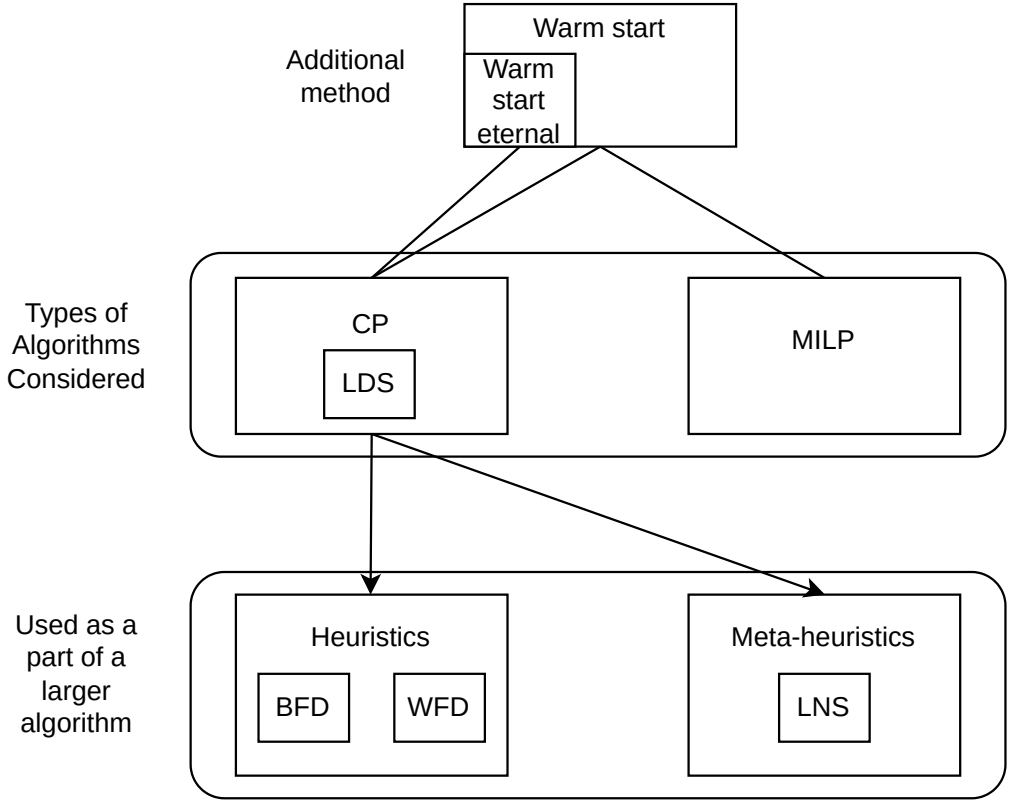
- Unlimited configuration
  - BinPacking problem
- Limited configuration
  - Multi-Knapsack problem



7.3 Work in progress

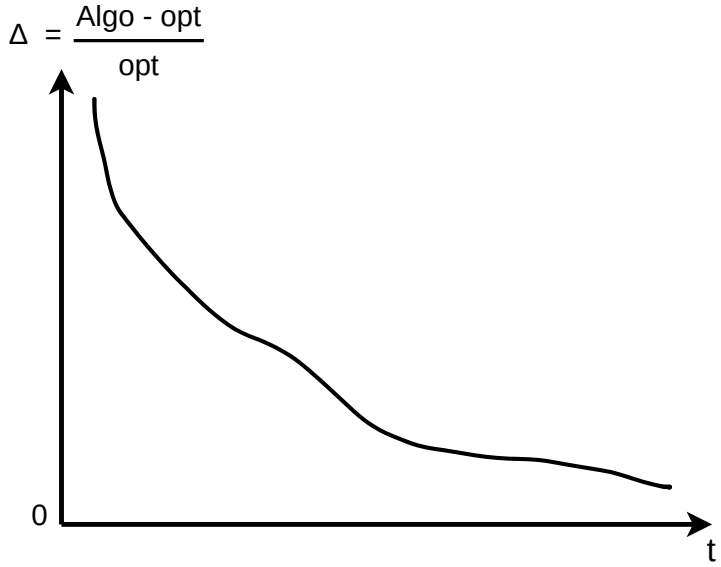


7.3 Work in progress



Metrics of interest:

- Anytime property
- Distance to the initial configuration



8. Sobriety, commons, and resilience

8.1 Context

Long term permanent resource unavailabilities

⇨ Need for alternatives to Cloud computing

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Long term permanent resource unavailabilities

⇨ Need for alternatives to Cloud computing

Collaboration with Deuxfleurs

- PEPR eNSEMBLE + NumEco
  - *Ph.D. of Lucien Astié*
- Digital commons (resilience)
- Limits-by-design (sobriety)

8.1 Context

Long term permanent resource unavailabilities

⇨ Need for alternatives to Cloud computing

Collaboration with Deuxfleurs

- PEPR eNSEMBLE + NumEco
  - *Ph.D. of Lucien Astié*
- Digital commons (resilience)
- Limits-by-design (sobriety)

Research question:

Sobriety ⇨ resilience (commons)?

Resilience (commons) ⇨ sobriety?

9. Conclusion

9.1 Concluding message

From resource infinity to ressources fluctuations

- New technical solutions to reconfigure, adapt, survive, recover...
  - Safety of reconfigurations
  - Resilience of reconfigurations
  - Timely constrained reconfigurations

... yes, but we also need to imagine and study completely new paradigms!

- Lowtech, sustainability, limits, etc.

9.2 People involved in ongoing work

- **Simon Artus**, Ph.D. student Orange, Melan [CoTerraform]
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- Erwan Brousse, Associate prof. Univ. Nantes [PEPR eNSEMBLE & NumEco]
- Sophie Cerf, CR Inria, Grenoble [PEPR Cloud & TASE]
- Baptiste Jonglez, Engineer Inria, Nantes [PEPR eNSEMBLE & NumEco, CoAnsible]
- **Sidi Mohammed Kaddour**, Engineer Inria, Nantes [CoAnsible]
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- Frédéric Loulergue, Professor Univ. Orléans [PEPR Cloud, Ballet, BPlan, ANR For-CoaLa]
- **Clément Mommessin**, Postdoc Inria, Grenoble [PEPR Cloud & TASE]
- **Eloi Perdereau**, Postdoc Univ. Orléans [BPlan, ANR For-CoaLa]
- Jolan Philippe, Associate prof., Univ. Orléans [Ballet, Koda, BPlan, ANR For-CoaLa]
- **Olivia Proust**, Ph.D. student, IMT Atlantique [ANR For-CoaLa]
- Charles Prud'homme, Associate prof., IMT Atlantique, Nantes [Ballet, Koda]
- **Nathan Rabier**, Ph.D. student Inria, Grenoble [PEPR Cloud & TASE]
- Eric Rutten, CR Inria, Grenoble [PEPR Cloud & TASE]
- Guido Salvaneschi, Professor St Gallen University, Switzerland [BPlan]
- Daniel Sokolowski, Researcher AWS, New York [BPlan]

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