NUCLEAR OF THE FUTURE INITIATIVES

Digital Reactor :

Perspectives and new challenges

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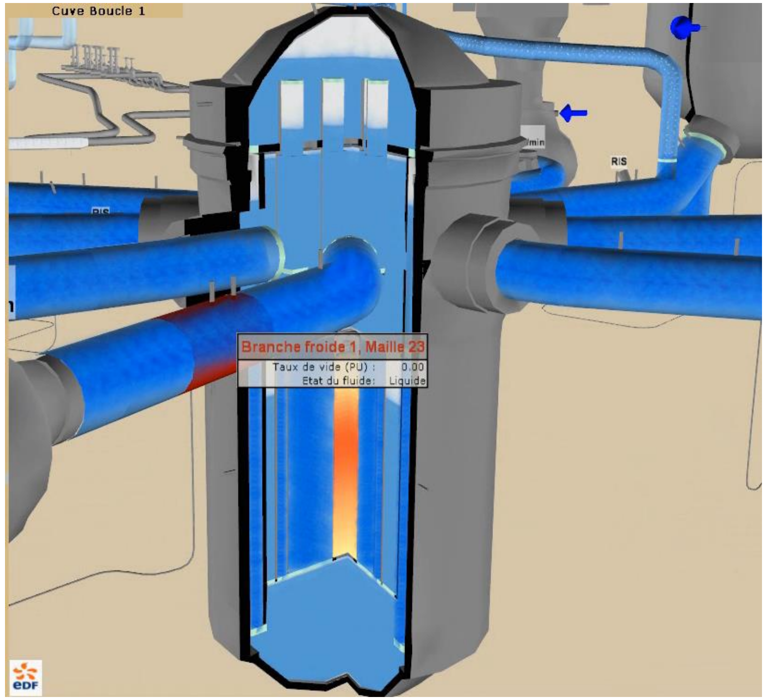

FRENCH NUCLEAR INSTITUTE
3P

EDF aneo the other solution

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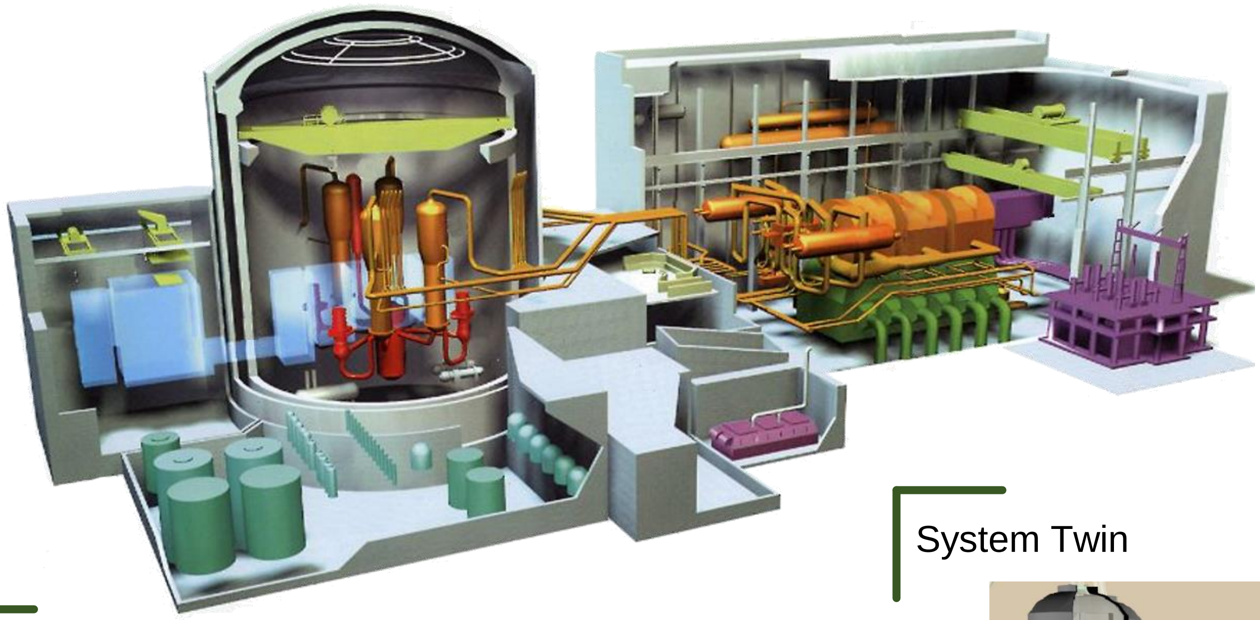
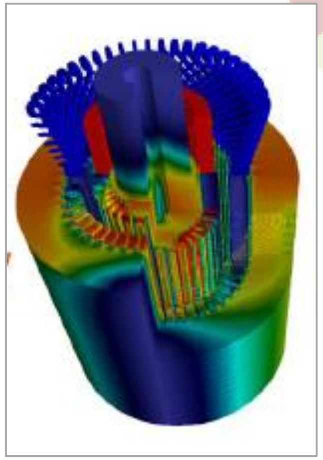
Different aspects of Digital Twins at EDF

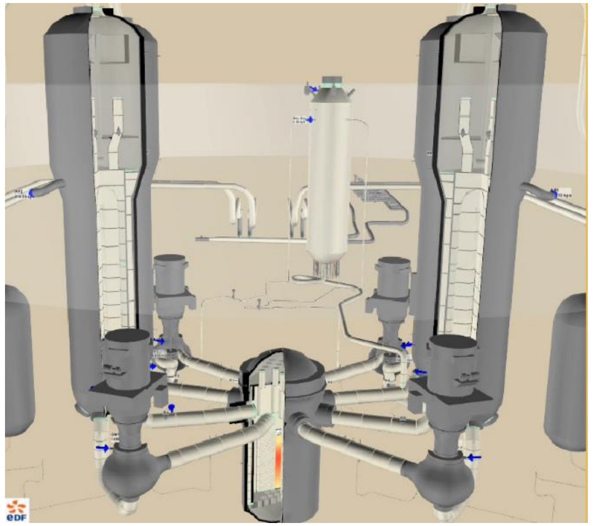
Digital Twins at EDF today



Component Twin (such as power generator)



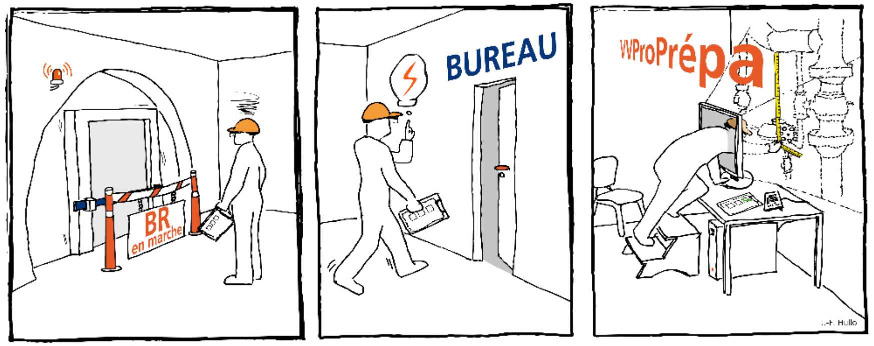
System Twin

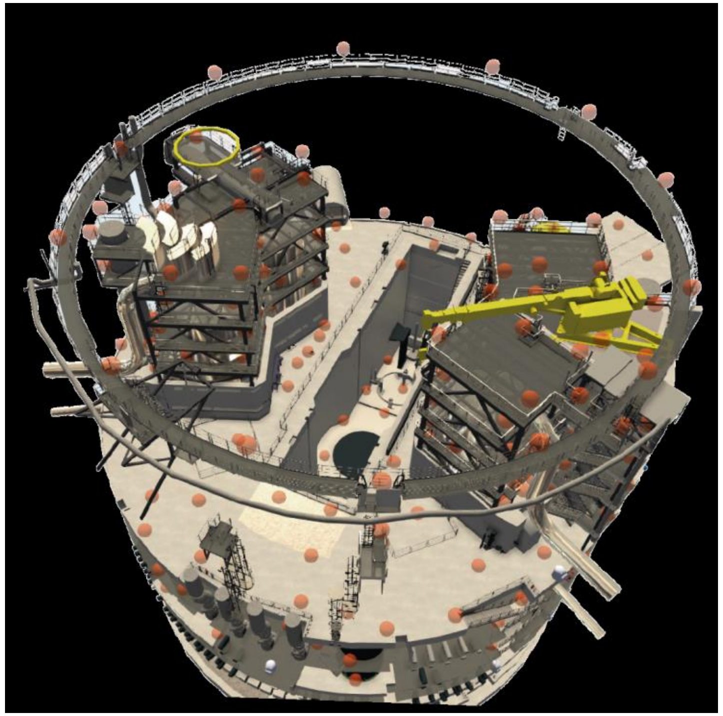


Reactor Building Twin

Digital twin for **Reactor Building** : VVProPrépa

- The inside of the reactor building is very complex and not accessible during normal reactor operations.
- However, <u>maintenance operations must be prepared in advanced in order to be efficient</u>. Solution is to have a virtual building.
- Thousands of very high definitions panoramic pictures (360°) have been taken to have a “Google Street” representation of the inside of the building.
- 3D laser scans have also been taken and imported inside the 3D real time Unity platform (technology from video game industry)
- Techniques allowing facility data, coming from different sources (such as pictures, laser scans, blueprints, clouds of points…), to be put in coherency has been the subject of a patent *Numerius* registered by EDF.
- One can then navigate inside the building, localize a piece of equipment, the path to get there, estimate the room available for operations, make annotations and so forth.





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New perspectives :

Digital Reactor for multi-physics core simulations

(French Nuclear Institute)

Reactor Simulations at EDF-CEA-FRA today

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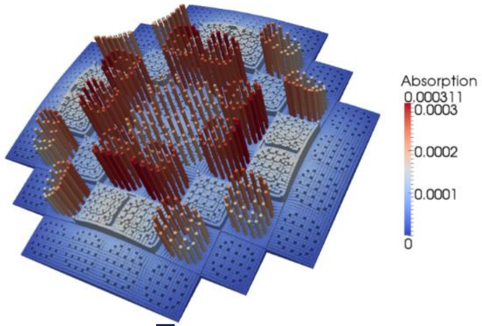
- Many codes for different physics (neutronics, mechanics, thermal-hydraulics) have been developed in house.
- Crossroads where computer power allows to break the walls between simulation types.

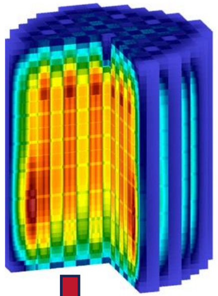
Higher physical representativeness

Best estimate



- Design Studies
- Reactor Design
- Accidents and safety studies

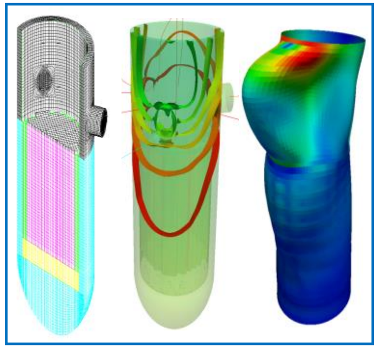
Best efforts



- Quantification of simulation biases
- Reference for safety studies

Interoperability / Interchangeability

High Fidelity



- Reference calculations
- Studies in extreme situations (accidents…)
- Substitute for experiments where no data are available

HPC challenges

- As seen in the previous slide all simulations use cases want to benefit from higher physical representativeness.
- Multi-physics coupling with some highly parallelized codes may require development of new algorithms as well as efficient data structures in order to prevent bottlenecks (we may have to rethink data workflow).
- The quantity of data used, exchanged and archived by the codes can reach up to terabytes for a single simulation. Data models need to be thought carefully if we want to be efficient.
- Efficient parallelization on computer clusters is very important for all codes since we need parametric calculations (in the order of millions for a single study).
- In the context of high parallelism, we have to start thinking how codes should handle hardware failures.
- In the future, hardware resources will probably be heterogeneous, we have to think “simulations in a cloud”

REX²C by ANEO

REX²C by ANEO

Runtime for Exascale Execution on Cloud

A runtime system for building next-generation HPC applications capable to leverage Cloud specificities

- The Cloud offers the following benefits for HPC :
  - Possibility to use 100, 000+ cores
  - Possibility to use resources tailored for the user workload
  - Efficient OPEX model
- With the following constraints :
  - Requires using pre-emptible instances for being economically competitive
  - Network performances are not similar to that of on premise supercomputers (except special cases)
- Scientific and technical concerns addressed are similar to the challenges presented by the advent of Exascale infrastructures :
  - Fault tolerance
  - Dynamic load balancing

REX²C by ANEO

Runtime for Exascale Execution on Cloud

A runtime system for building next-generation HPC applications capable to leverage Cloud specificities

- Rex²C: Cache

A layer on top of existing filesystem allowing to efficiently cache data using peer to peer protocol

- Rex²C: Runtime

Propose to HPC application developers a runtime system capable to handle a dynamic load balancing and to manage an elastic infrastructure

- Rex²C: Workflow

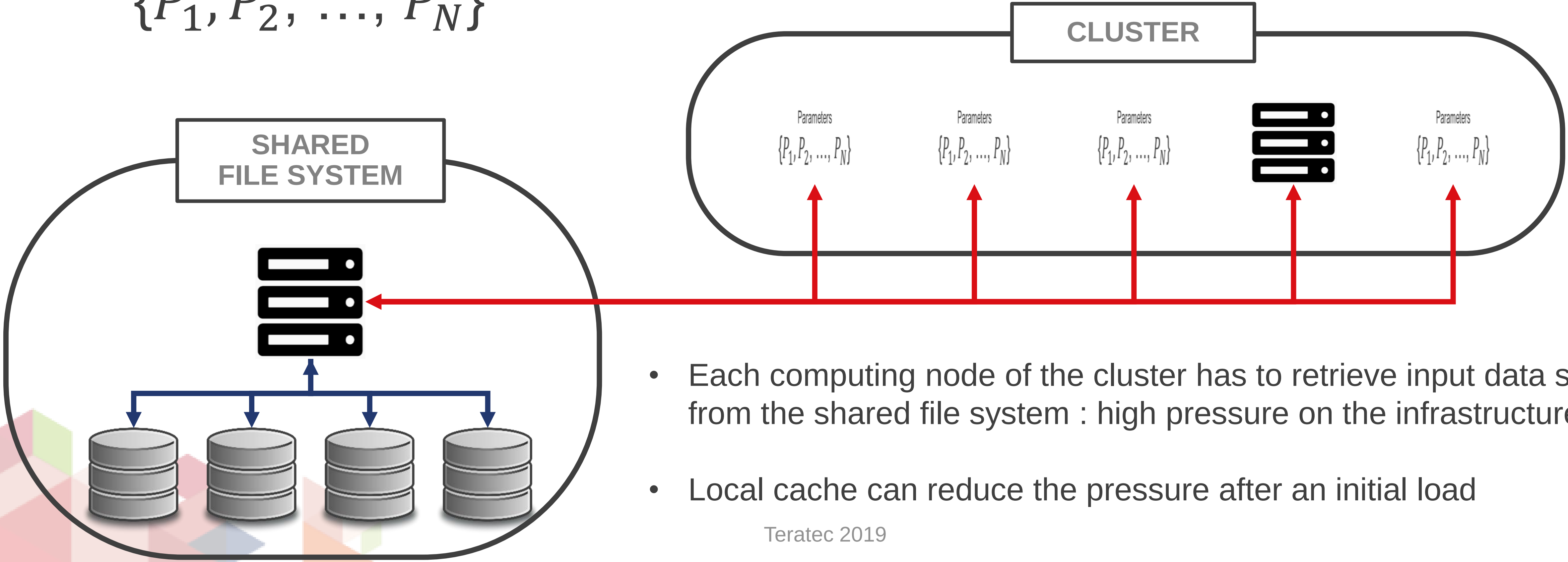
A framework for composing multiple applications

Challenge I : Large Parametric Simulations

Millions of independent simulations, each corresponding to a different set of parameters, will be executed :

Parameters

$$\{P_1, P_2, \ldots, P_N\}$$



- Each computing node of the cluster has to retrieve input data set from the shared file system : high pressure on the infrastructure
- Local cache can reduce the pressure after an initial load

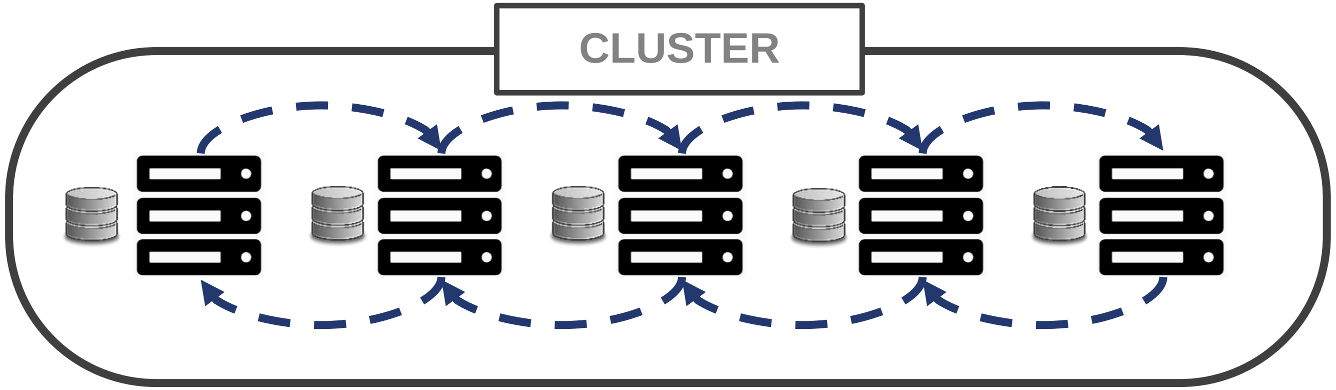
ANEO REX²C: Cache

Runtime for Exascale Execution on Cloud

Rex²C: Cache : a layer on top of existing filesystem allowing to efficiently cache data using peer to peer protocol

File access workflow :

1. The application uses a client for contacting the file server
2. Rex²C: Cache checks for permissions and file availability
3. Rex²C: Cache checks if file is already available on other nodes (belonging to the current session) and download from there where appropriate
4. Otherwise download the file from the underlying filesystem



Rex²C: Cache must handle metadata operations

ANEO REX²C: Cache

Runtime for Exascale Execution on Cloud

Rex²C: Cache must satisfy the following properties :

- Each computing node must be able to identify another one and keep its neighboring nodes up to date in case of failure
- Local cache cleanup must take into account file availability on other computing nodes
- Metadata operations (e.g.: add/remove directory or file) must be performed locally for performance purposes
- In case of concurrent access on the same file, precedence must be guaranteed
- File access rights must be maintained for security
- When running in the Cloud, data caching must be carefully handled to comply with local regulations

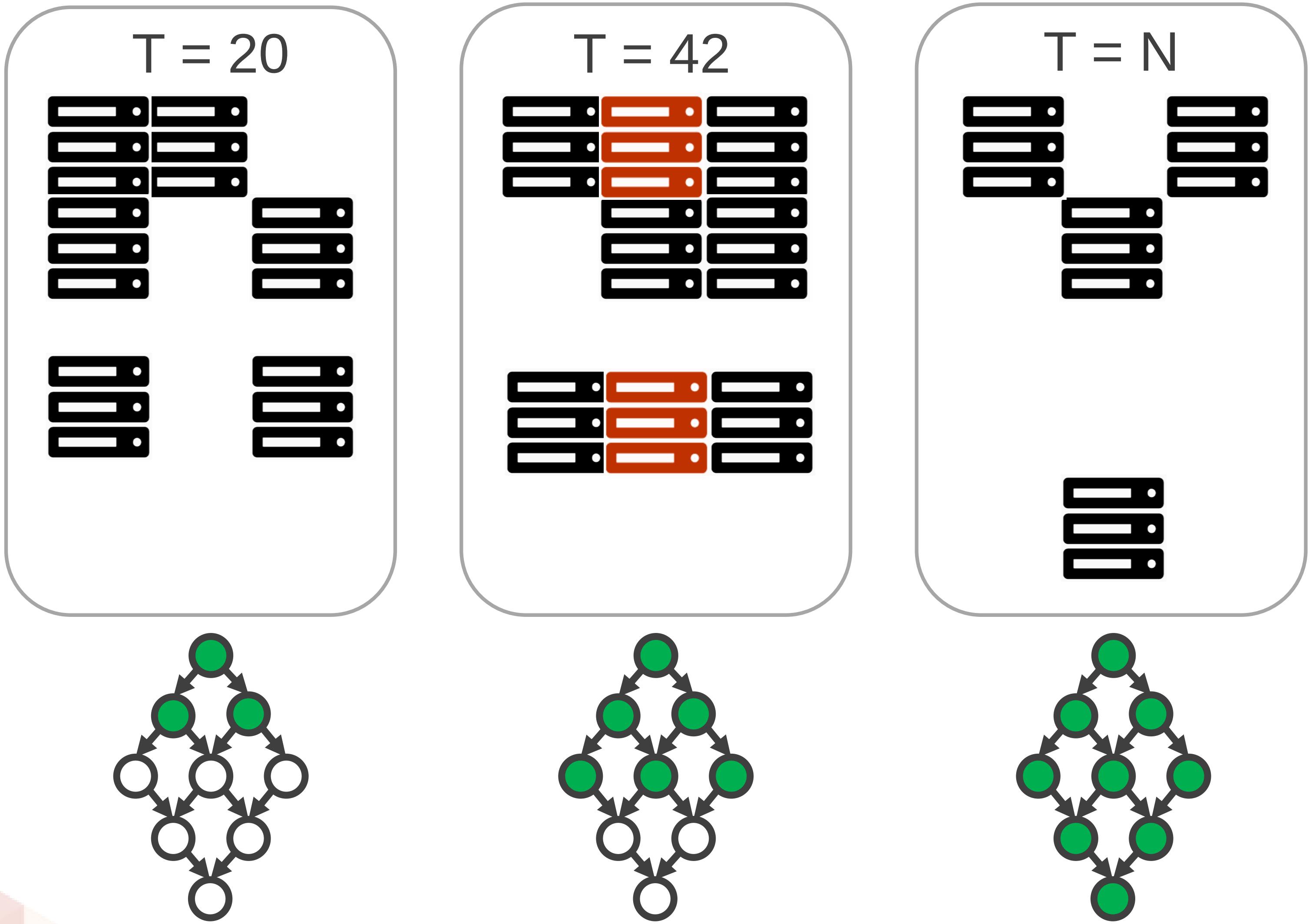
Challenge II : Fault tolerance and Load balancing

Major points of interests :

- Mean-Time Between Failure (MTBF) on modern clusters are becoming very short (few minutes)
- Heterogeneous computing nodes within the same cluster, leading to heterogeneous workload execution time
- Physical and numerical approaches (e.g.: adaptive mesh refinement) requires sometimes non-uniform workload distribution over the cluster

Challenge II : Fault-tolerence and Load balancing

Executing a task-graph on elastic infrastructure



ANEO REX²C: Runtime

Runtime for Exascale Execution on Cloud

Core features of Rex²C: Runtime

- Transparently handle task migration from one computing node to another one
- The DAG of tasks must be dynamically re-partitioned after it has been fully distributed over the cluster
- For performance purposes (minimizing failure impact and leveraging preemtible instances), optimal checkpointing of the DAG of tasks must be computed on the fly

Conclusion

Building Exascale-ready HPC software infrastructure for the Digital Reactor

Building the Digital Reactor highlights several HPC challenges :

- Multi-physics coupling
- Large scale parametric simulations on supercomputers (and Cloud)

Tackling these challenges leads to the development of Rex²C :

- A runtime system for next-generation HPC applications
- Capable to leverage both on premise supercomputers and Cloud
- Capable to handle node failures and dynamic load balancing

Thanks,
any question?

Appendixes

System thermal-hydraulic twin

- EDF utilizes CATHARE code for modelling of the steam generator, primary circuit and some auxiliary circuit.
- CATHARE (Code for Analysis of Thermal-hydraulics during an Accident of Reactor and safety Evaluation) is a two-phase thermal-hydraulic simulator.
- Developed at CEA and part of an agreement between the CEA, EDF, AREVA and the IRSN.
- Extensive V&V using facilities such as BETSY (Grenoble)
- Embedded in simulators and used extensively for operators training and accident studies.
- Pedagogic visualization (*visualization metaphors*) is very important to understand physics, as the simulation runs