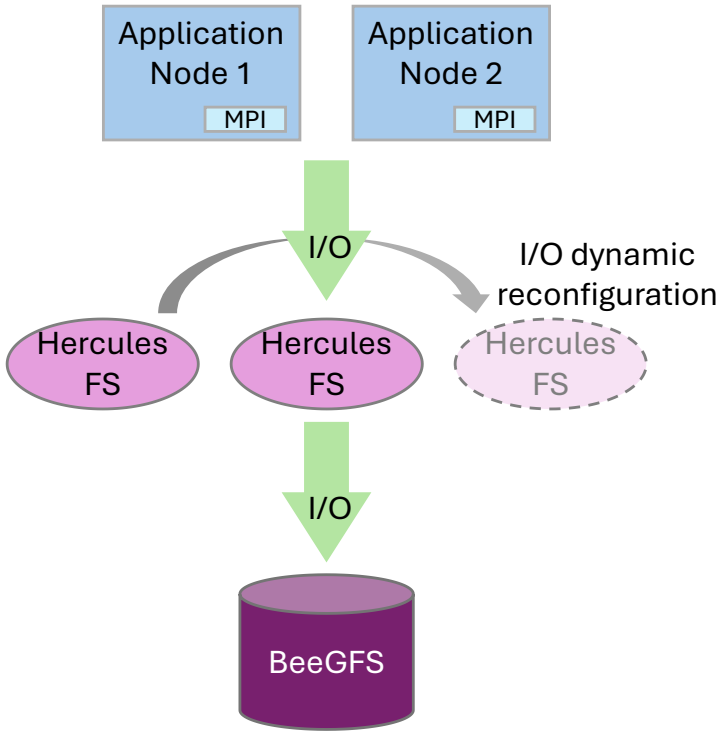
Exploring Combined Dynamic Resource Management in Applications and File Systems

Paula Sanchez-Checa, Genaro Sanchez-Gallegos, Javier García-Blas,
Jesús Carretero and **David E. Singh**


CLINT EASTWOOD
THE GOOD THE BAD and THE UGLY
co-starring
LEE VAN CLEEF
also starring
ELI WALLACH
in the role of TUCO
directed by
SERGIO LEONE

The Good: Hercules

- Ad-hoc in-memory filesystem
- Captures POSIX I/O calls
- I/O and metadata servers
- UCX as communication library
- Dynamic reconfiguration capabilities



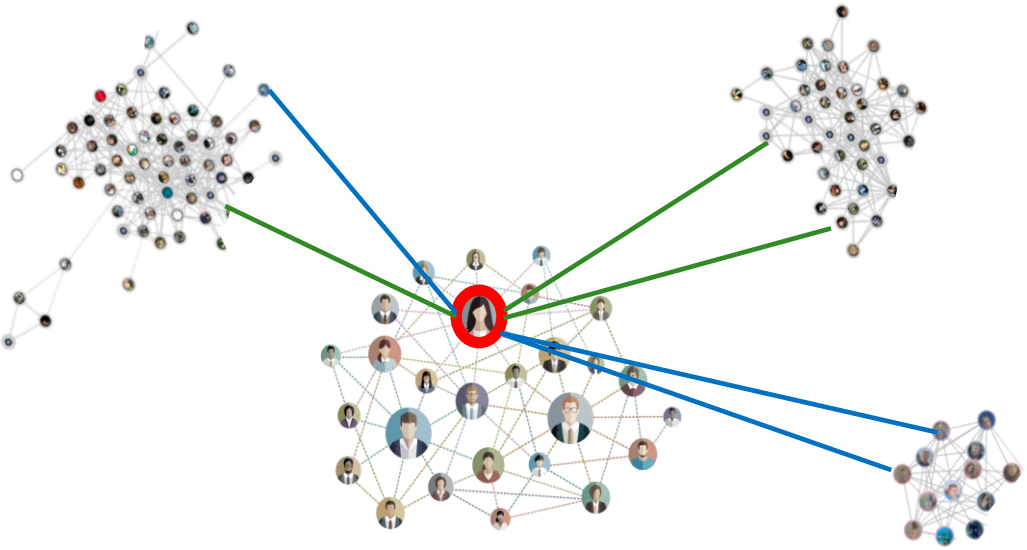
https://gitlab.arcos.inf.uc3m.es/admire/hercules

The Bad: EpiGraph

- Agent-based epidemiologic simulator
- Multiple COVID-19 variants
  Extended to model Influenza and RSV
- Social model built from social networks and contact matrices
- Collaboration with ECDC, Spanish Ministry of Health, and National Epidemiology Center

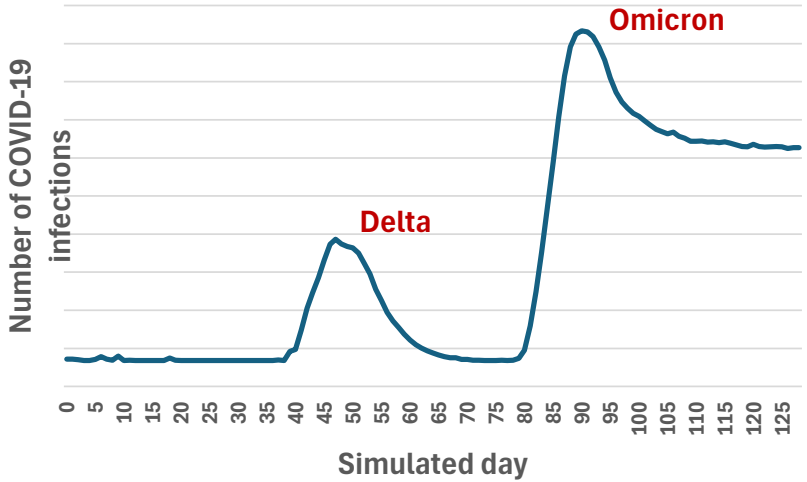
EpiGraph

- EpiGraph simulation scenario
  - SARS-CoV-2 Omicron variant outbreak in Spain in November 2021
  - Madrid city
  - 3.5 million individuals



Why EpiGraph is bad?

- EpiGraph alternates
  - CPU: 10 minutes (simulated time)
  - Communication: every simulated hour
  - I/O: every simulated hour



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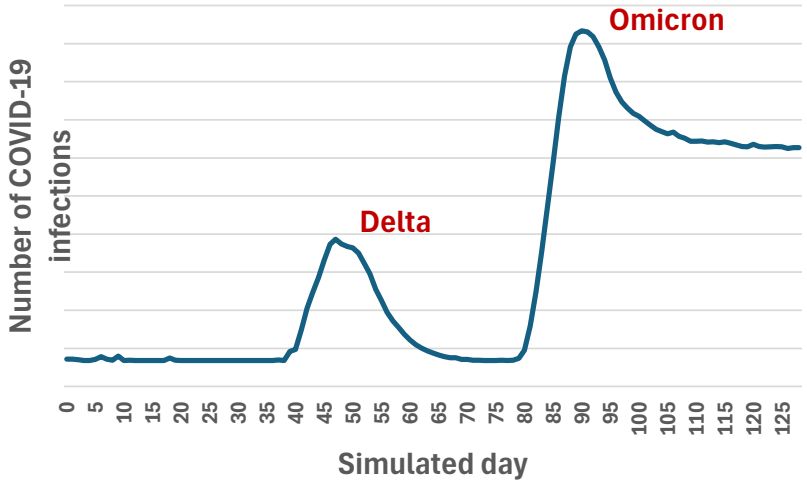

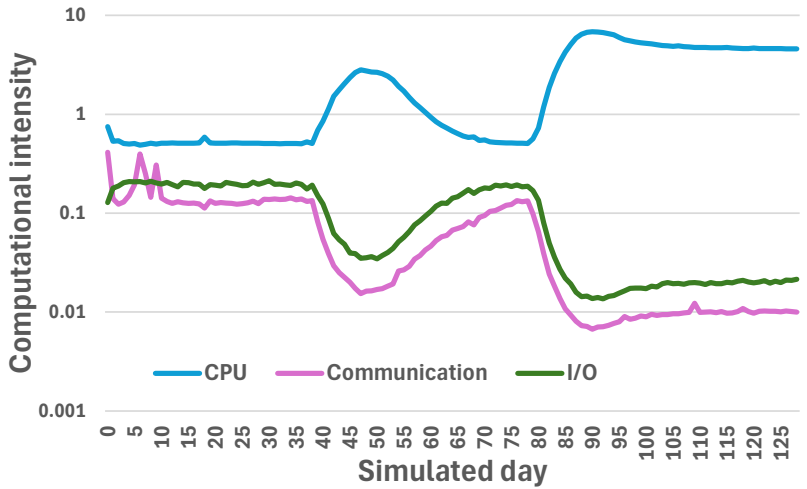

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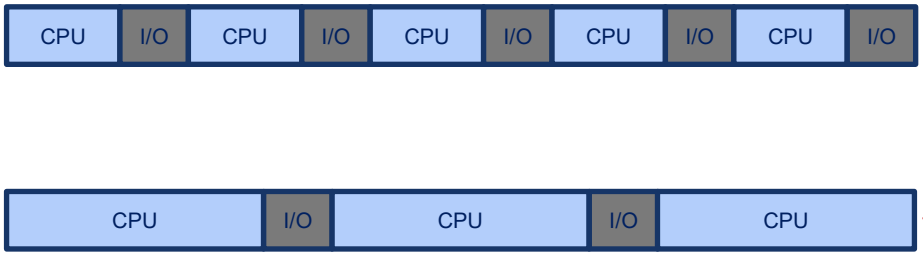

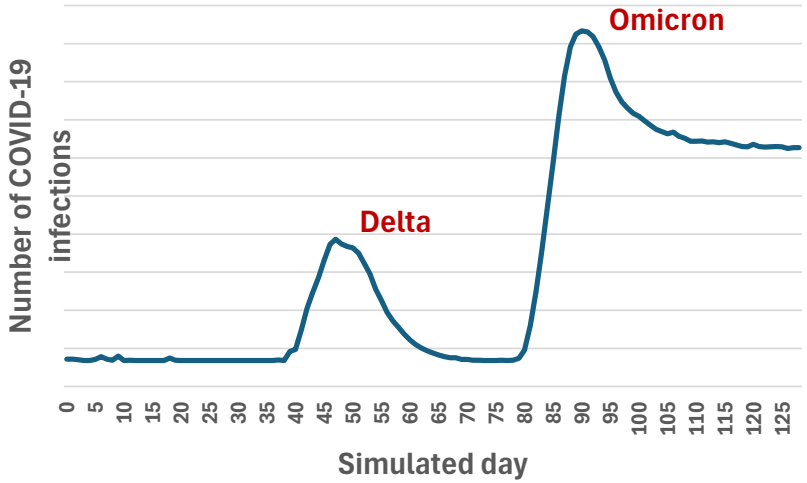

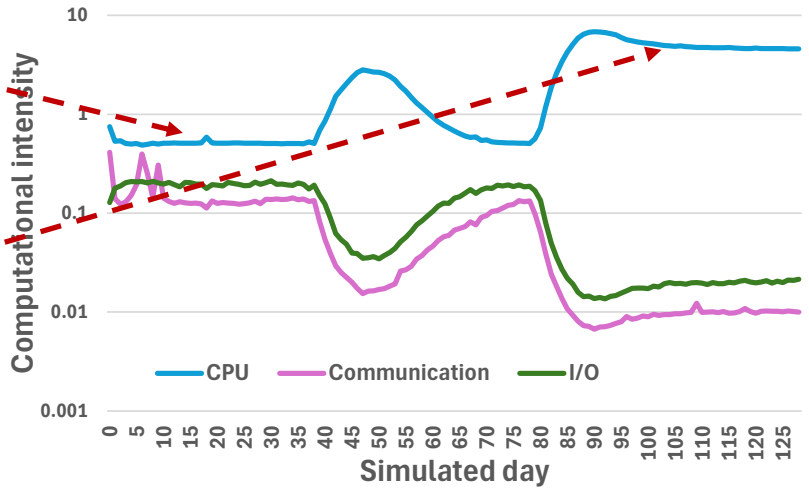

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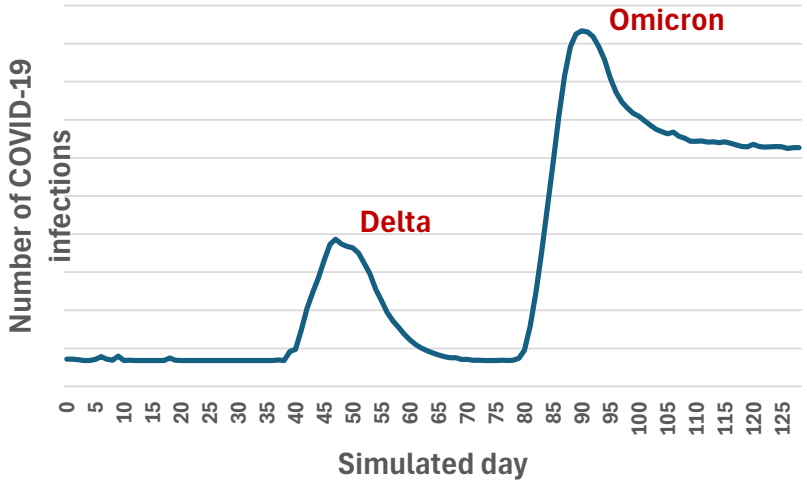
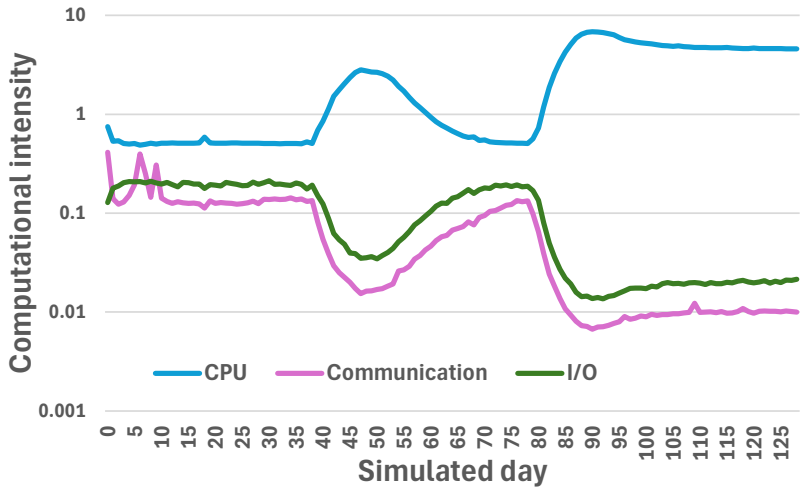
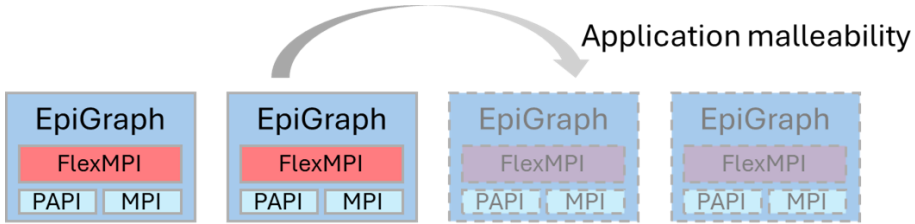
How many computational and I/O resources do we use?





EpiGraph

- EpiGraph executed with **FlexMPI**
  - Dynamically increasing or reducing the number of processes
  - Automatic data redistribution



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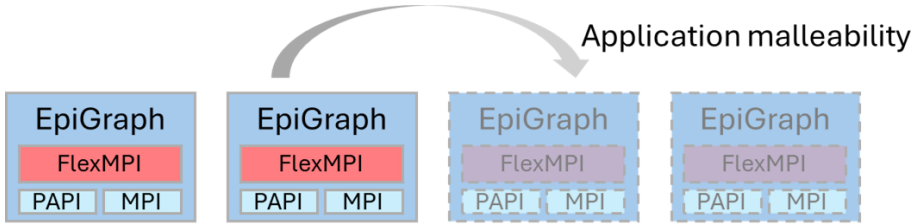

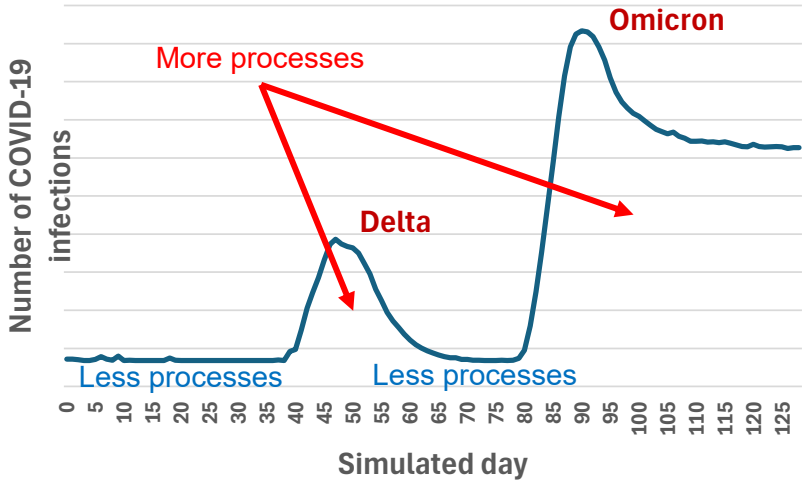

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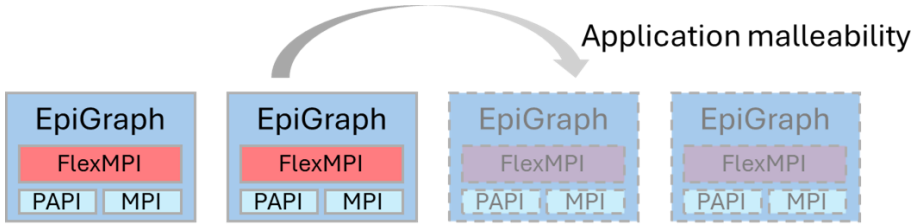
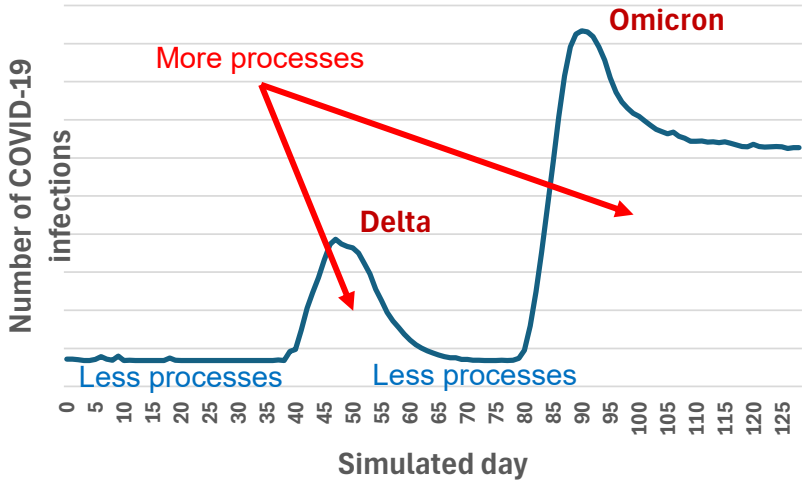
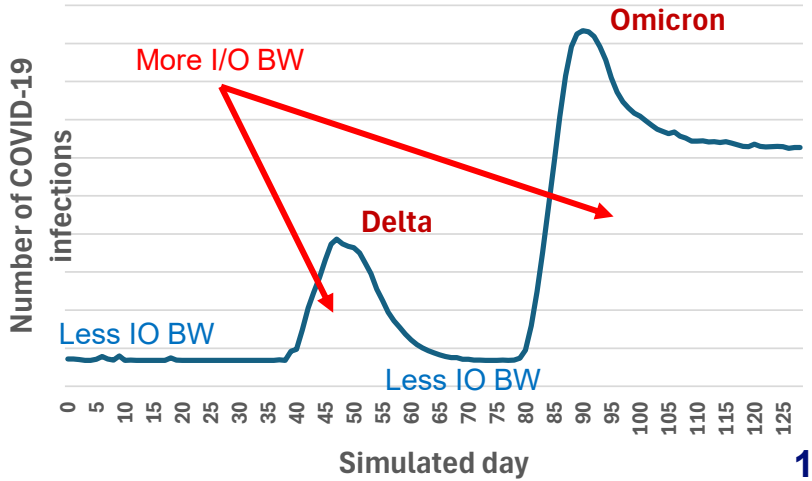
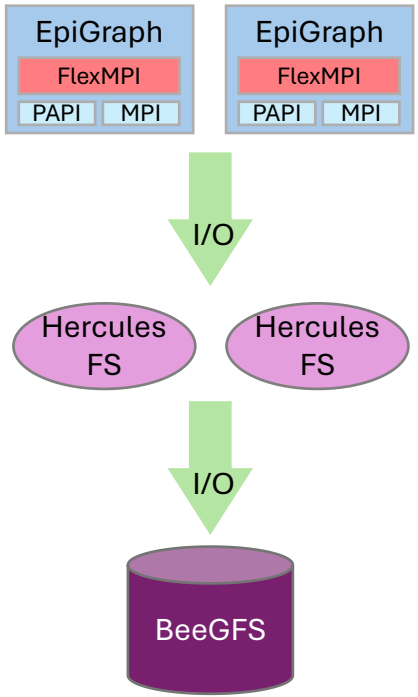
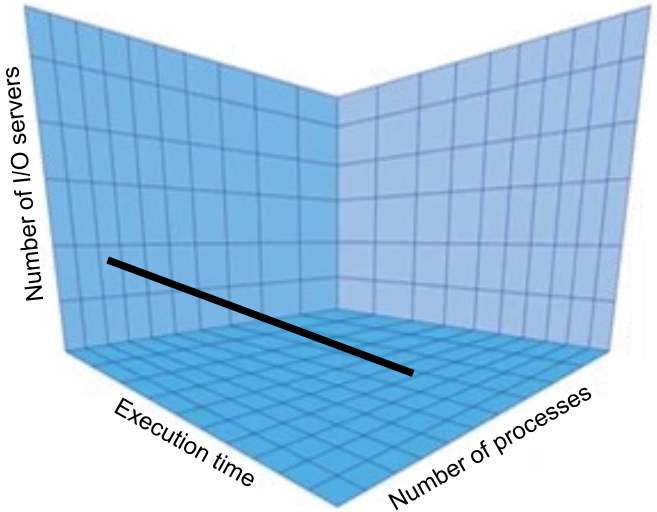




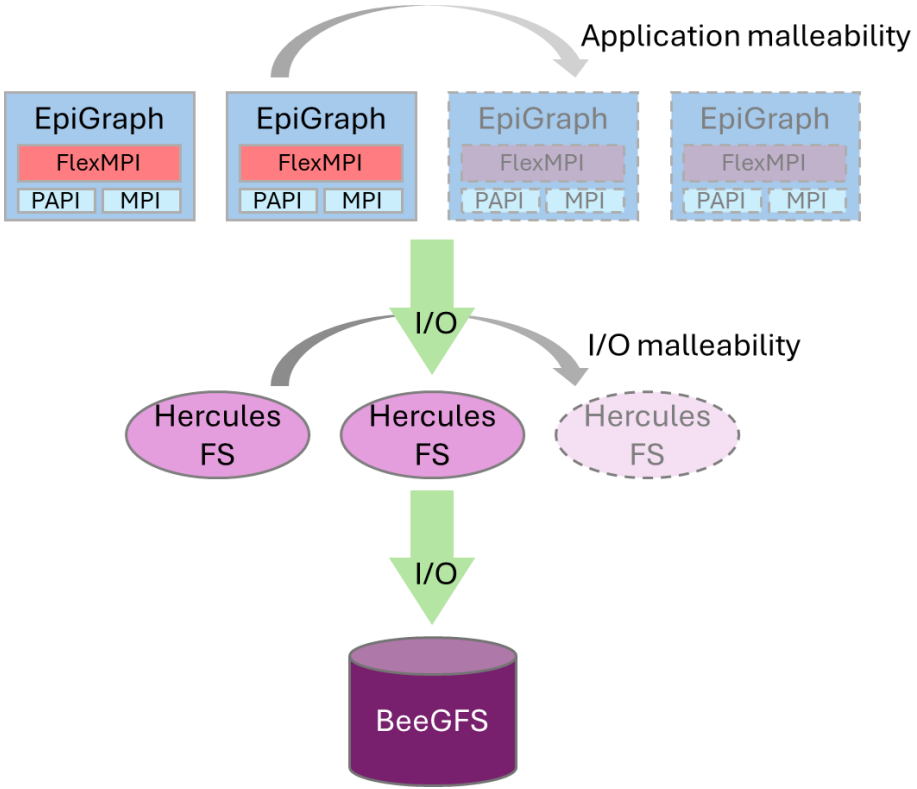


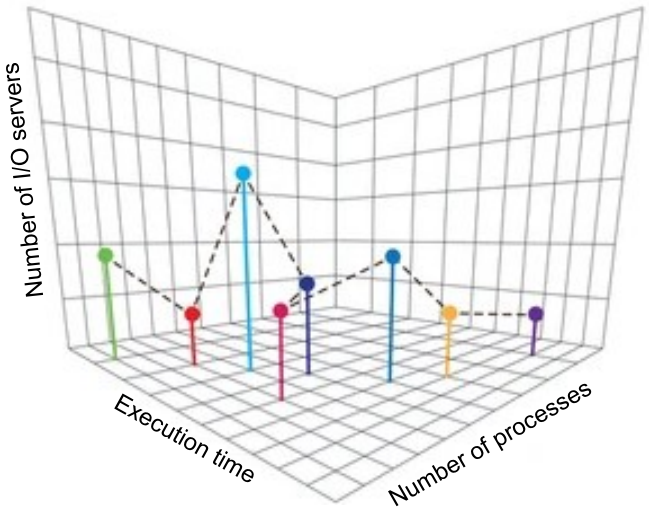
Static execution





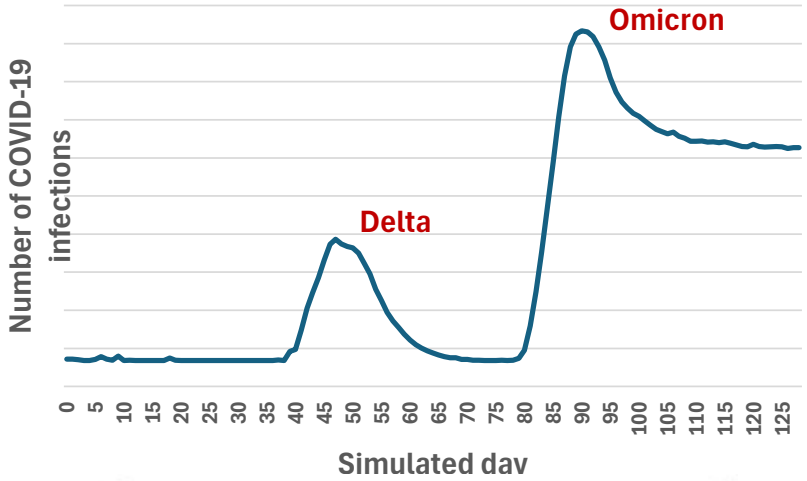
The Ugly: dynamic execution

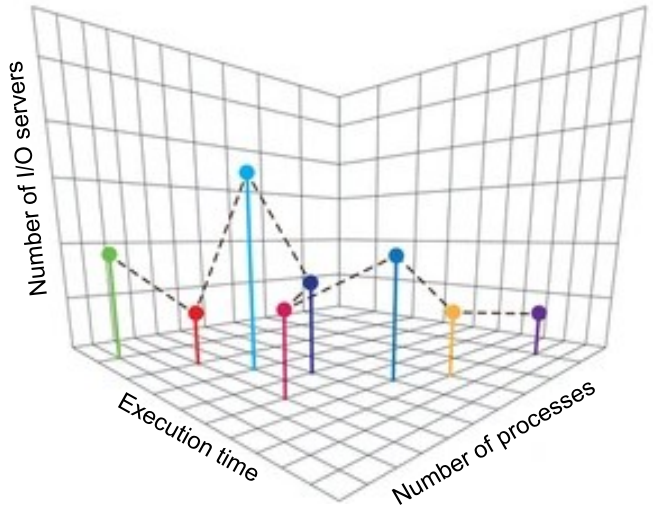




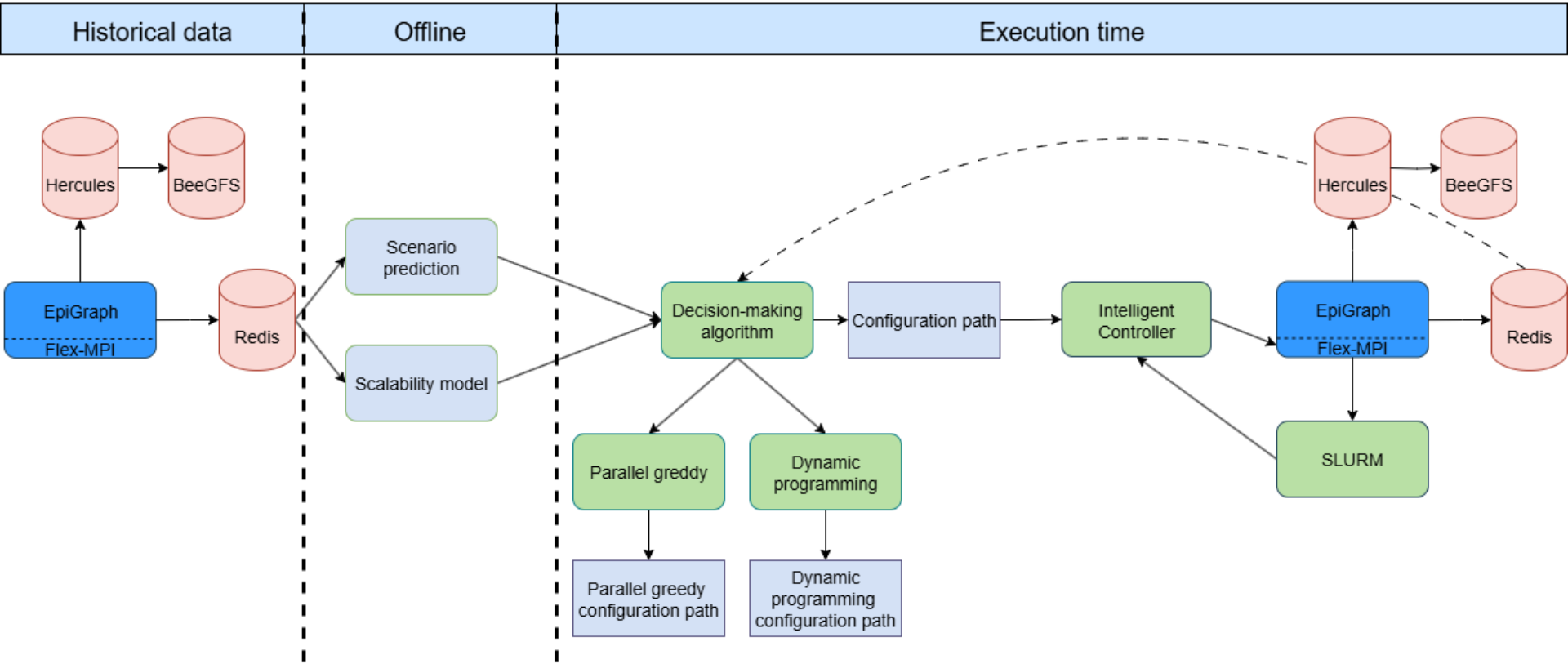
Challenges

- Identify the application behaviour in run-time
- Consider multiple performance metrics
  - CPU, I/O and communication time
  - Resource utilisation
  - Overheads
- Make the decision in run-time
  - Finding the best configuration path





Proposed workflow



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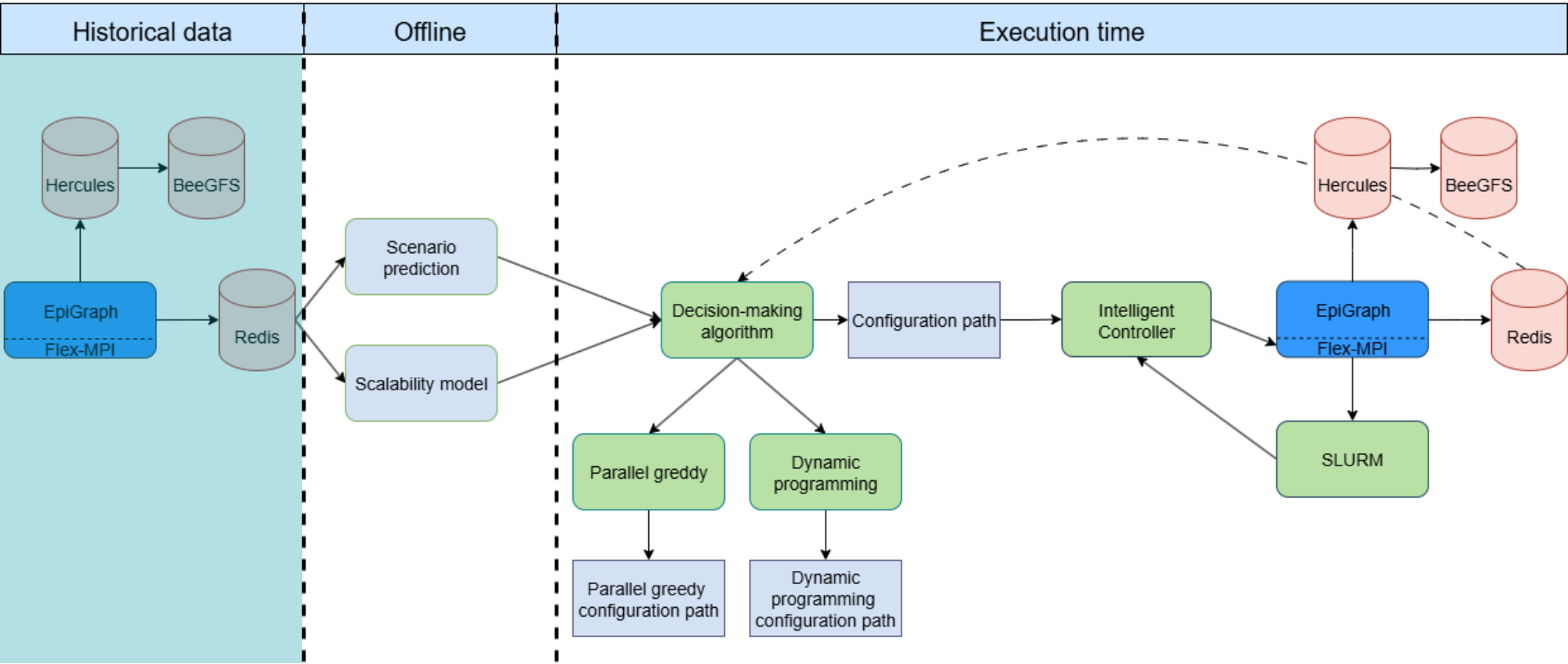
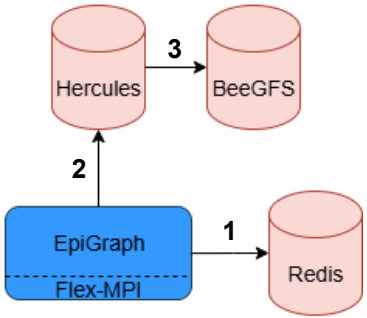


Workflow

1. Application performance metrics.

2. I/O operations on Hercules.

3. Persistent storage of simulation results.



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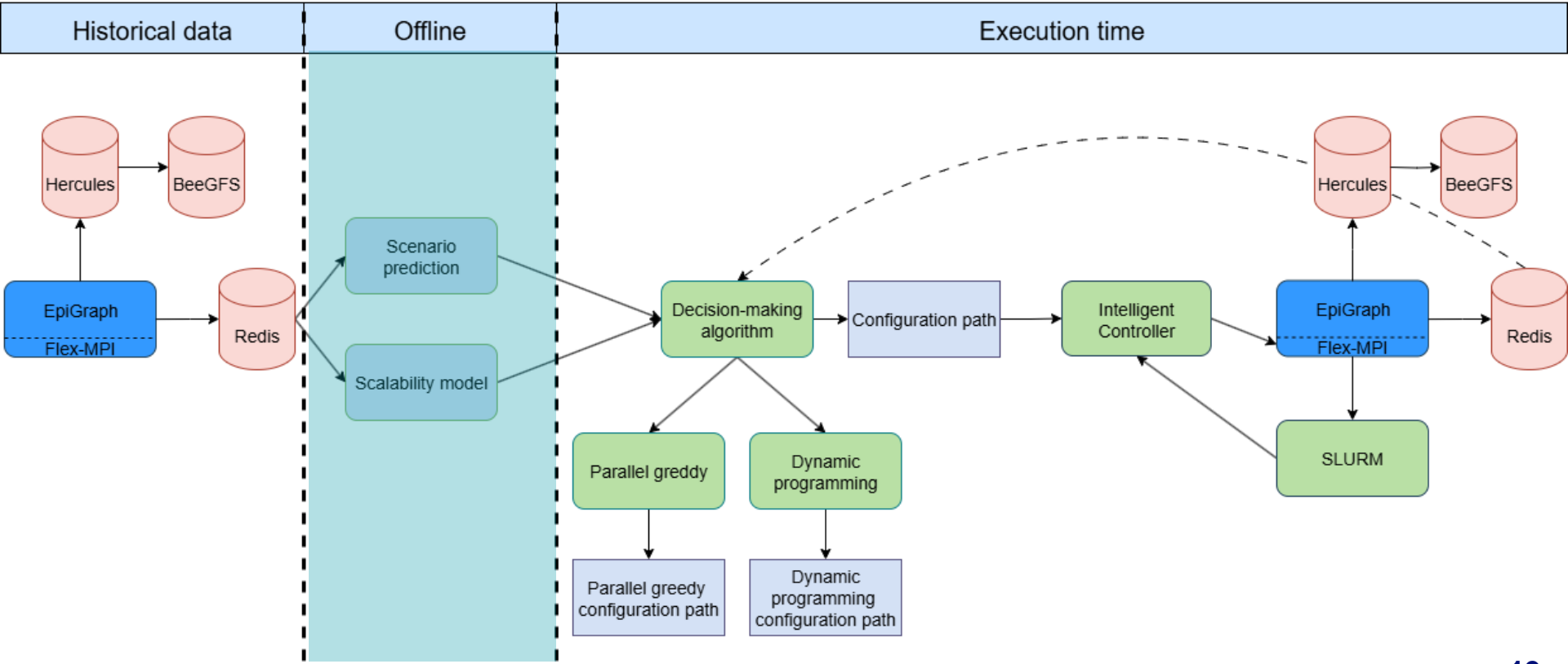
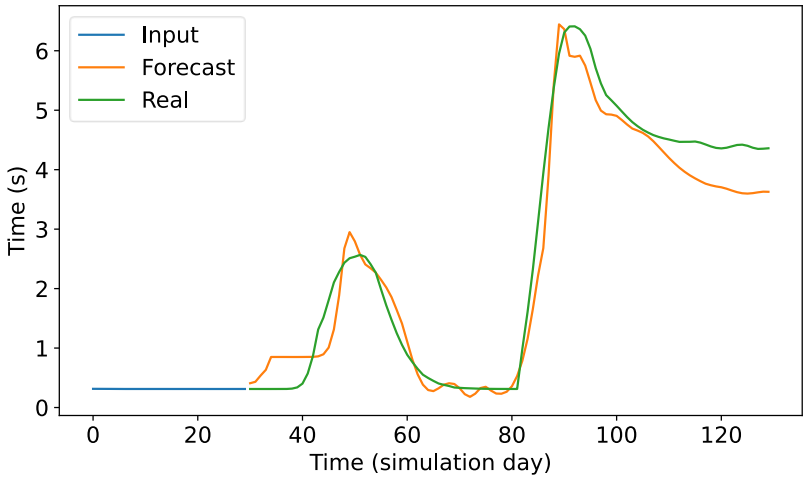


Scenario prediction

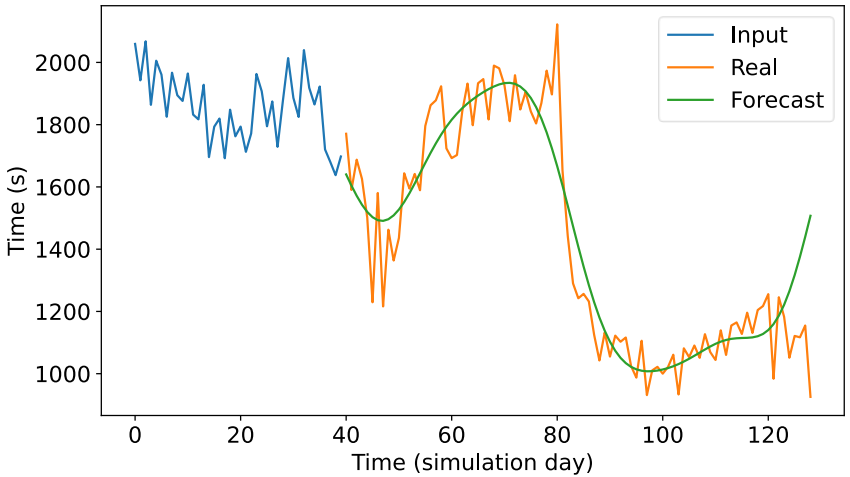
CPU time

- Long Short-Term Memory NN
- RMSE: 5,5



Communication time

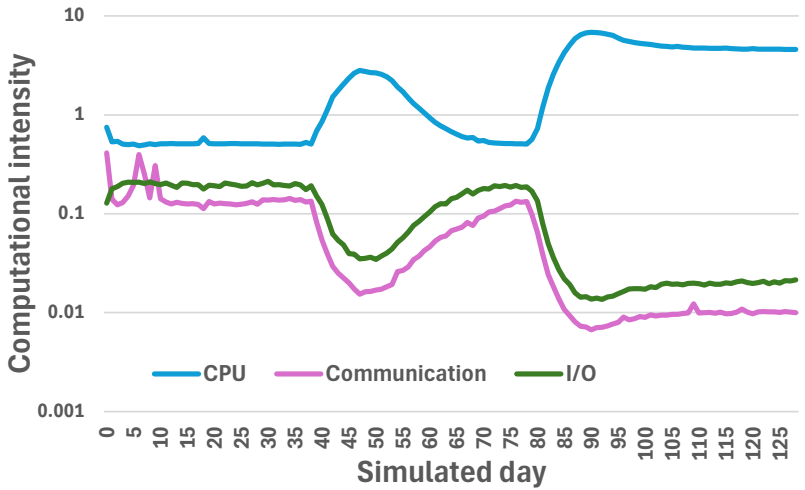
- Low-pass filter
- RMSE: 1,3



Scalability model

- Performance metrics related to different configurations
  - Number of processes (EpiGraph)
  - Number of I/O nodes (Hercules)

- Numerical fitting (like Extra-P)
  - Considering multiple configuration paths
  - Considering different EpiGraph execution phases



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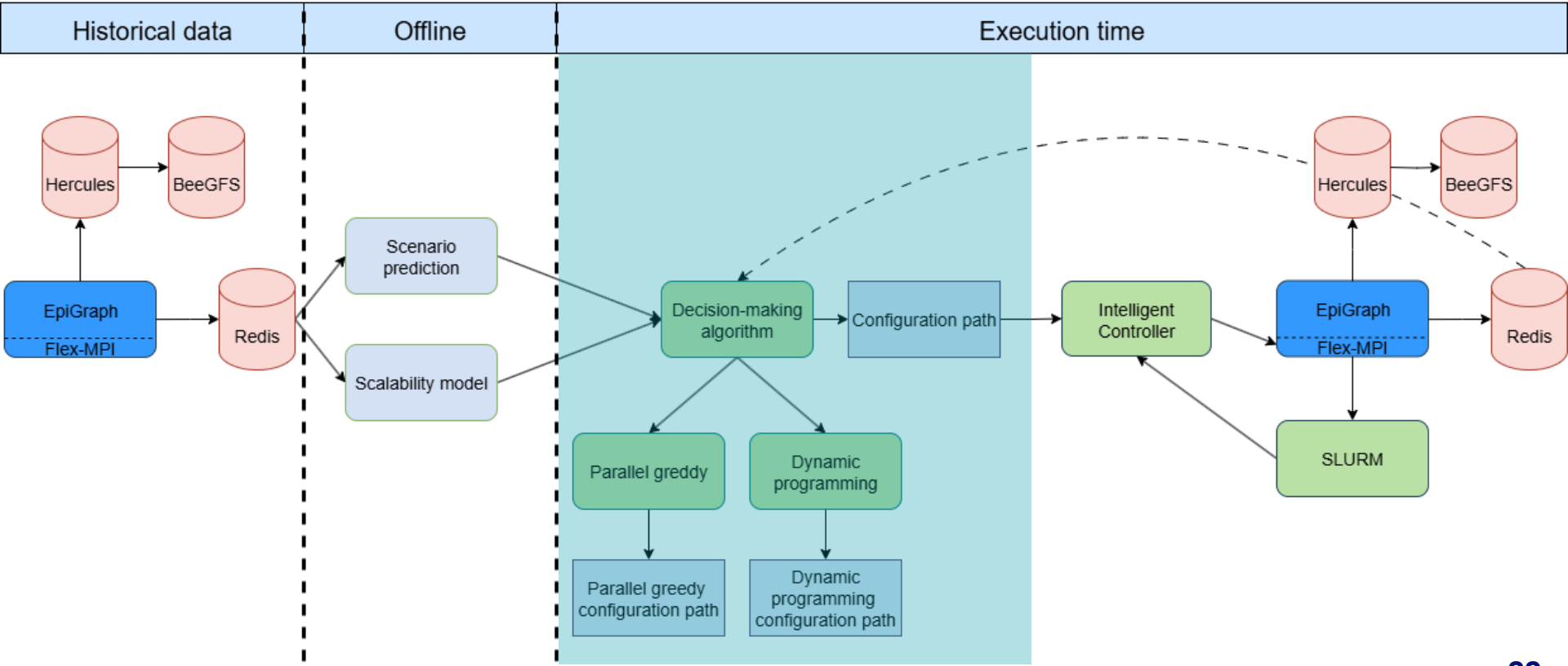
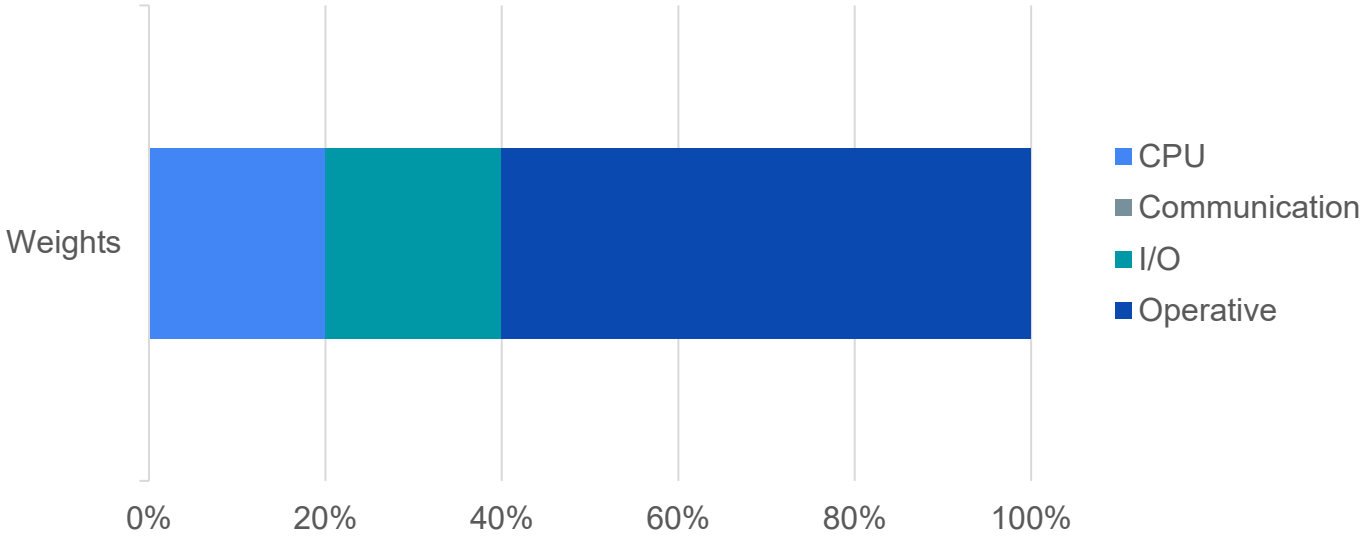


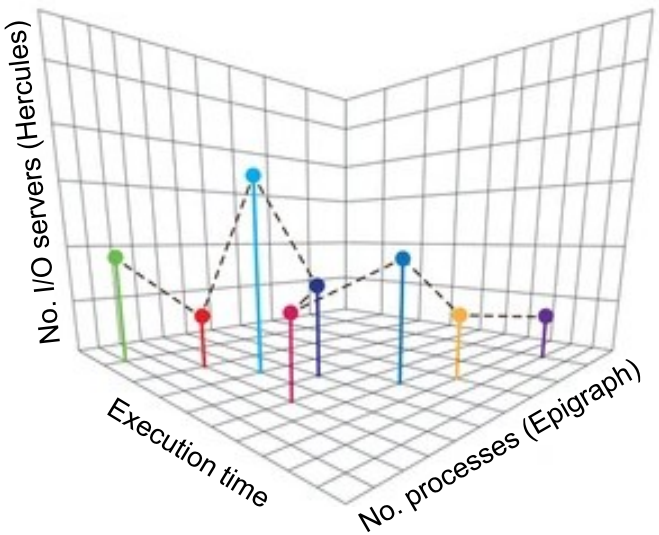
Optimization cost

$$\begin{cases} c_t^i = \alpha \cdot t_{cpu} + \beta \cdot t_{com} + \gamma \cdot t_{io} + \delta \cdot t_{op} \\ \alpha + \beta + \gamma + \delta = 1 \end{cases}$$



Configuration path

- Two algorithms
  - Parallel greedy algorithm
  - Dynamic programming search



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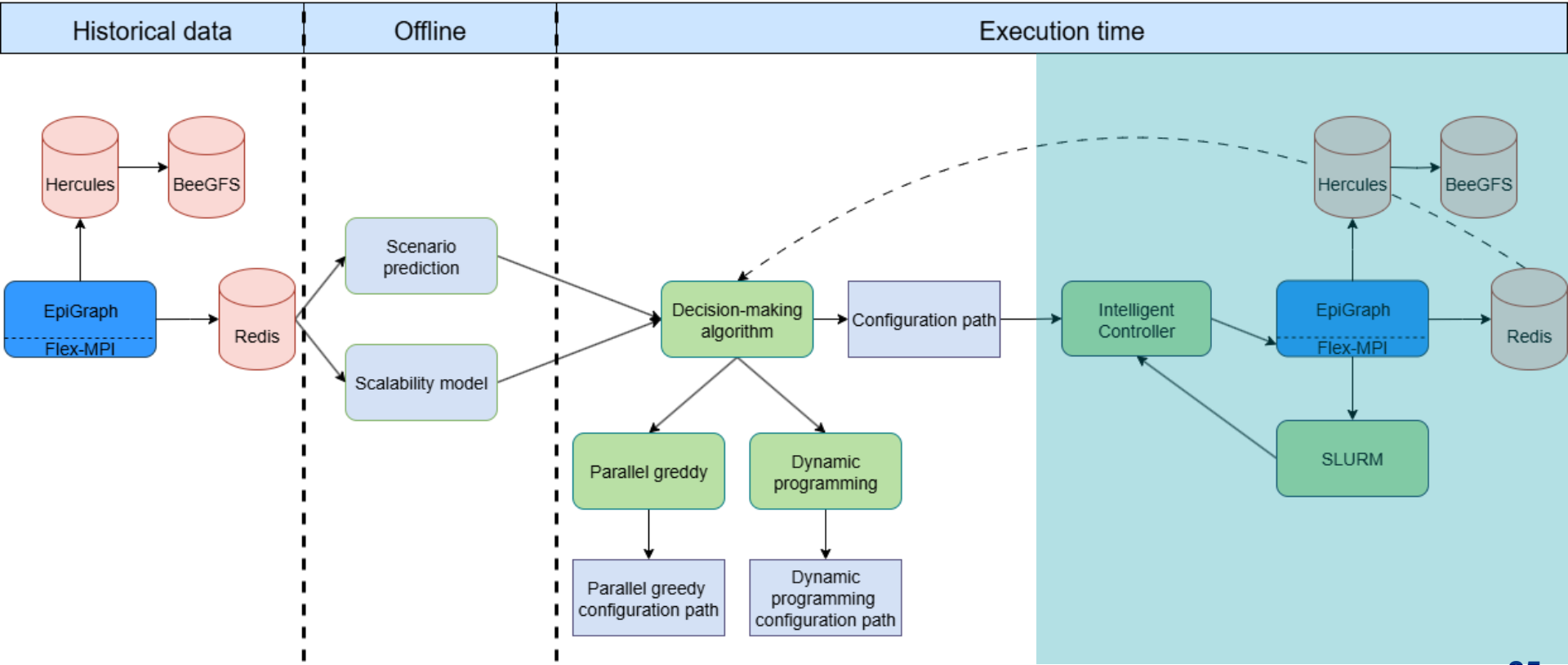

Evaluation

- HPC4AI Laboratory, Universidad di Torino

Id	Initial configuration	(α,	β,	γ,	δ)	Execution time (s)	Operational time (s)	Reconfigurations
1	**(1, 2)**	**(-,**	**-,**	**-,**	**-)**	**507**	**2.447**	———
2	(1, 2)	(1,	0,	0,	0)	338	3.000	$(1, 2) \xrightarrow{40} (8, 4)$
3	(1, 2)	(0,	0,	1,	0)	338	3.000	$(1, 2) \xrightarrow{40} (8, 4)$
4	(1, 2)	(0.4,	0,	0.4,	0.2)	338	3.000	$(1, 2) \xrightarrow{40} (8, 4)$
5	(1, 2)	(0.2,	0,	0.2,	0.6)	325	1.651	$(1, 2) \xrightarrow{40} (5, 4) \xrightarrow{84} (5, 2)$
6	(1, 2)	(0.1,	0,	0.1,	0.8)	294	1.547	$(1, 2) \xrightarrow{41} (5, 2)$
7	**(2, 4)**	**(-,**	**-,**	**-,**	**-)**	**483**	**2.835**	———
8	(2, 4)	(1,	0,	0,	0)	329	3.145	$(2, 4) \xrightarrow{40} (8, 4)$
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11	(2, 4)	(0.2,	0,	0.2,	0.6)	321	1.747	$(2, 4) \xrightarrow{42} (5, 4) \xrightarrow{84} (5, 2)$
12	(2, 4)	(0.1,	0,	0.1,	0.8)	305	1.633	$(2, 4) \xrightarrow{42} (3, 4) \xrightarrow{84} (5, 2)$
13	**(8, 4)**	**(-,**	**-,**	**-,**	**-)**	**379**	**4.210**	———
14	(8, 4)	(1,	0,	0,	0)	379	4.210	(8, 4)
15	(8, 4)	(0,	0,	1,	0)	379	4.210	(8, 4)
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17	(8, 4)	(0.2,	0,	0.2,	0.6)	383	2.472	$(8, 4) \xrightarrow{40} (5, 4) \xrightarrow{84} (5, 2)$
18	(8, 4)	(0.1,	0,	0.1,	0.8)	382	2.495	$(8, 4) \xrightarrow{40} (3, 4) \xrightarrow{82} (5, 2)$

Evaluation: minimizing I/O time

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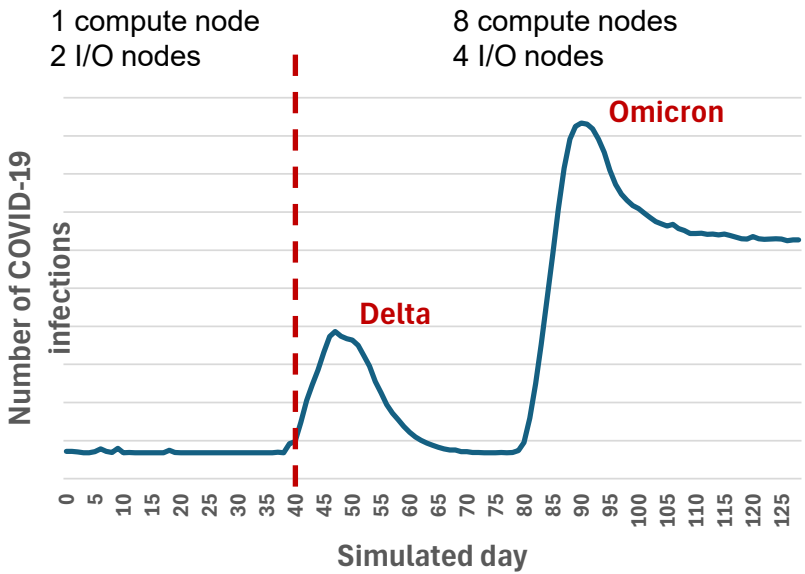
Evaluation: minimizing I/O time

$$(1,\ 2) \xrightarrow{40} (8,\ 4)$$

	Static execution	Dynamic execution
Execution time	507 s	338 s
I/O time	21s	12s
Operative time	2.447 s	3.000 s



Evaluation: balance CPU, I/O and OT

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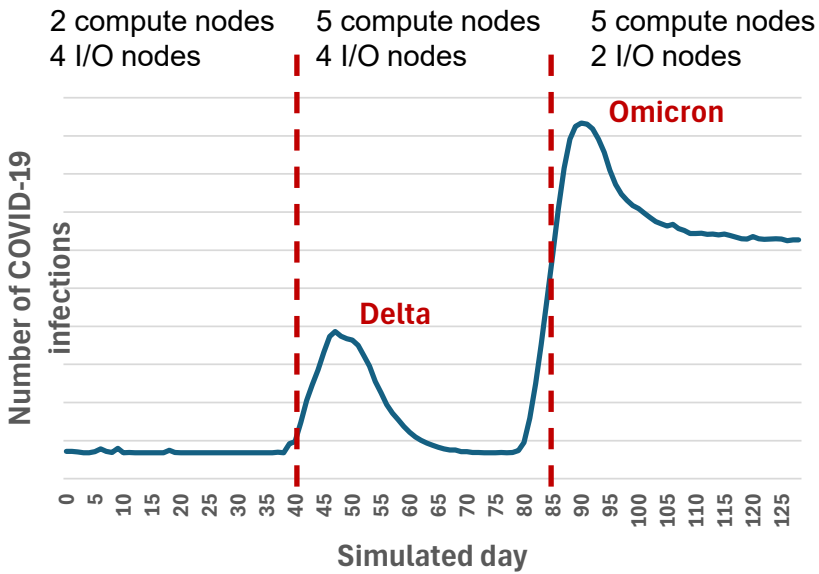
17	(8, 4)	(0.2,	0,	0.2,	0.6)	383	2.472	$(8, 4) \xrightarrow{40} (5, 4) \xrightarrow{84} (5, 2)$
18	(8, 4)	(0.1,	0,	0.1,	0.8)	382	2.495	$(8, 4) \xrightarrow{40} (3, 4) \xrightarrow{82} (5, 2)$

Evaluation: balance CPU, I/O and OT

$$(2,\ 4) \xrightarrow{42} (5,\ 4) \xrightarrow{84} (5,\ 2)$$

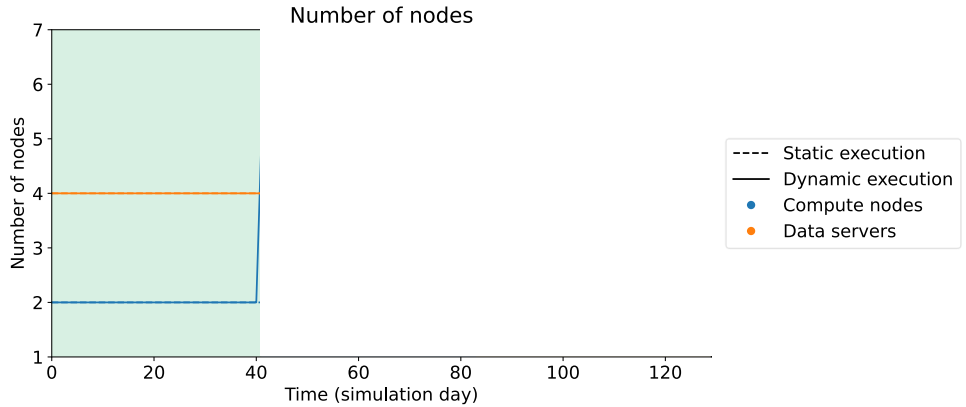
	Static execution	Dynamic execution
Execution time	483 s	321 s
Operative time	2.835 s	1.747 s

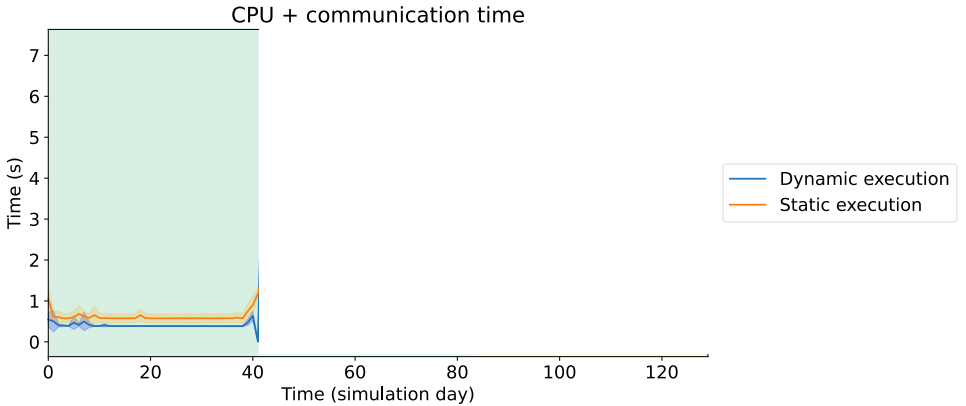


Evaluation

CPU vs communication times

$$(2,\ 4) \xrightarrow{42} (5,\ 4) \xrightarrow{84} (5,\ 2)$$

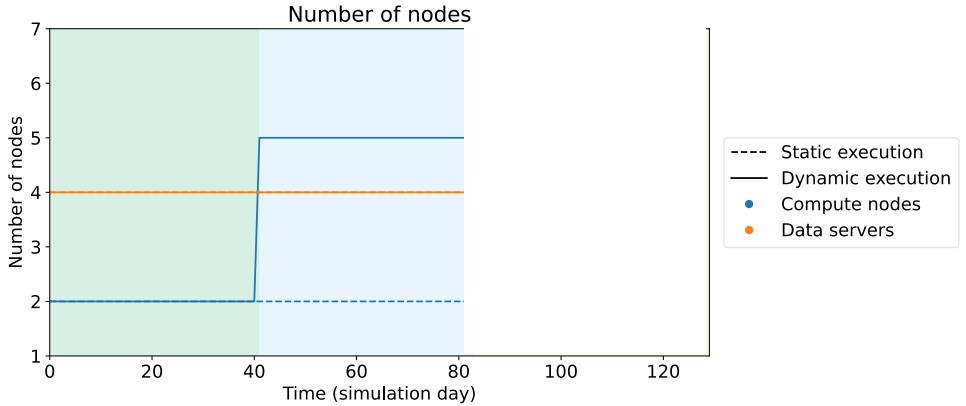


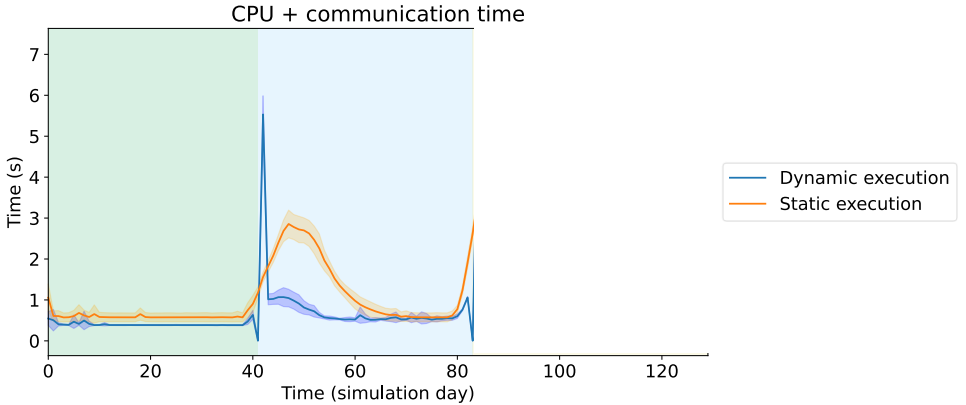


Evaluation

CPU vs communication times

$$(2,\ 4) \xrightarrow{42} (5,\ 4) \xrightarrow{84} (5,\ 2)$$

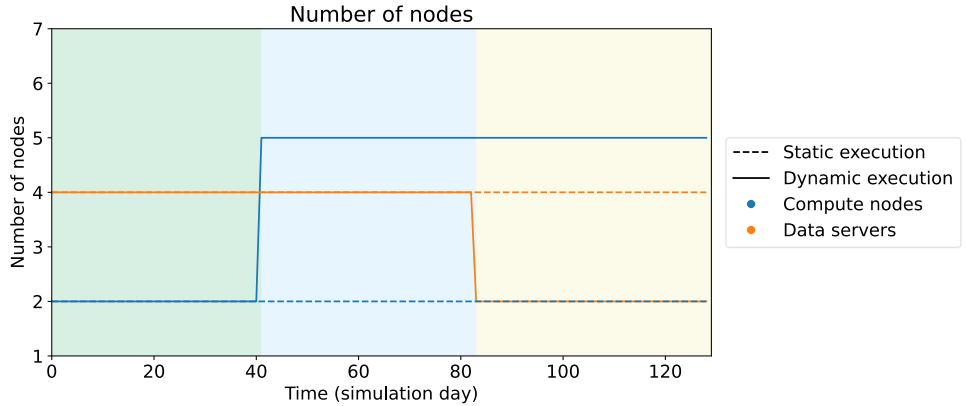


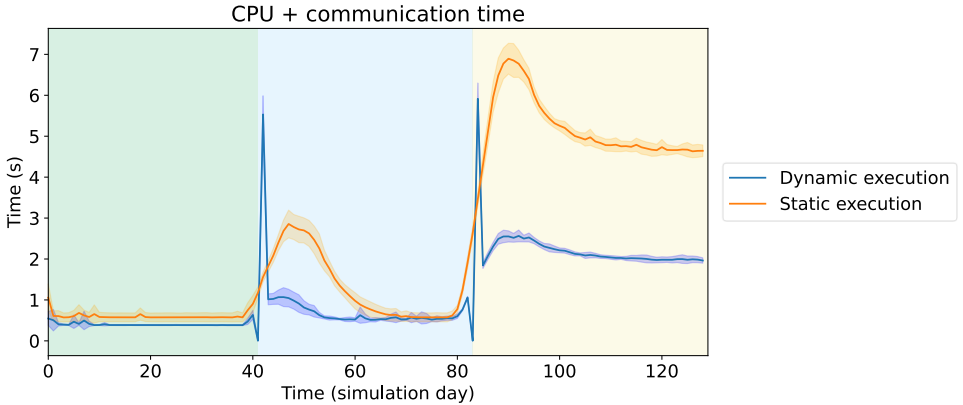


Evaluation

CPU vs communication times

$$(2,\ 4) \xrightarrow{42} (5,\ 4) \xrightarrow{84} (5,\ 2)$$

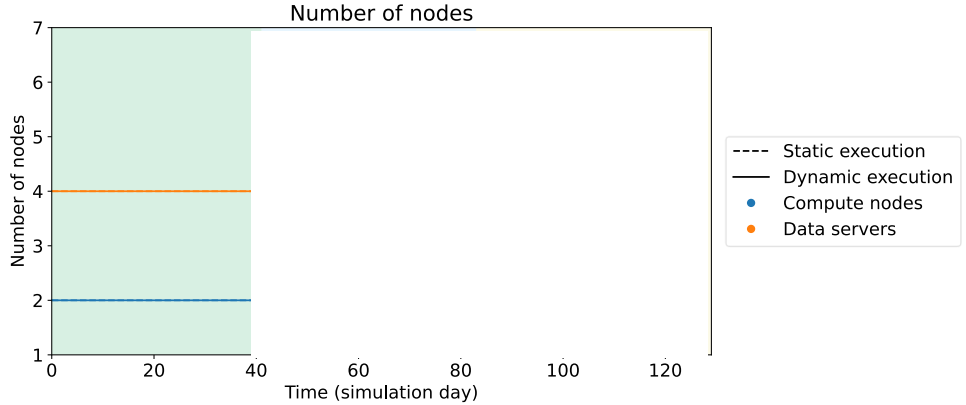


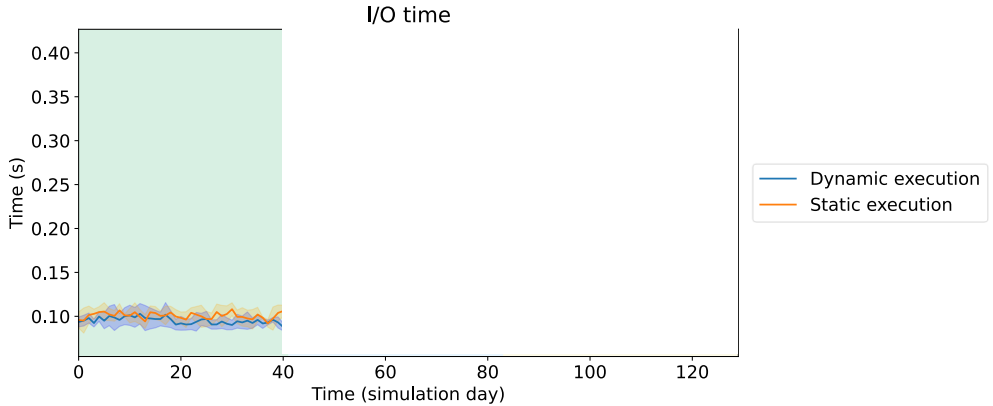


Evaluation

CPU vs I/O time

$$(2,\ 4) \xrightarrow{42} (5,\ 4) \xrightarrow{84} (5,\ 2)$$

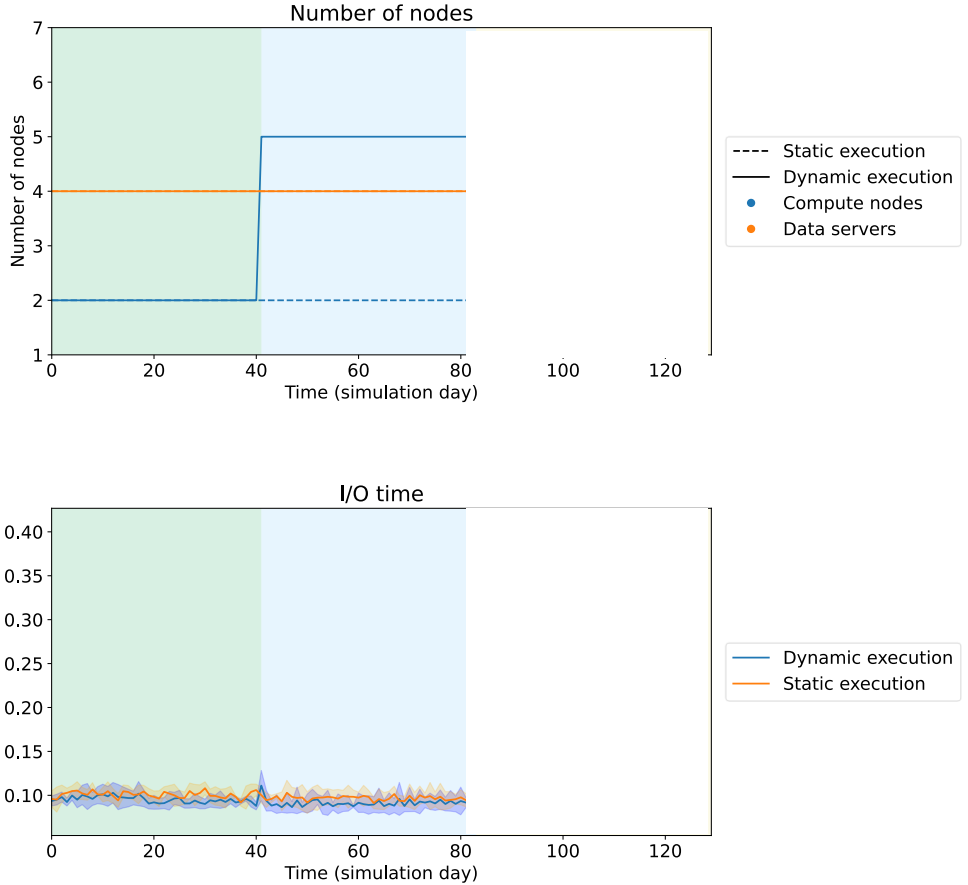




Evaluation

CPU vs I/O time

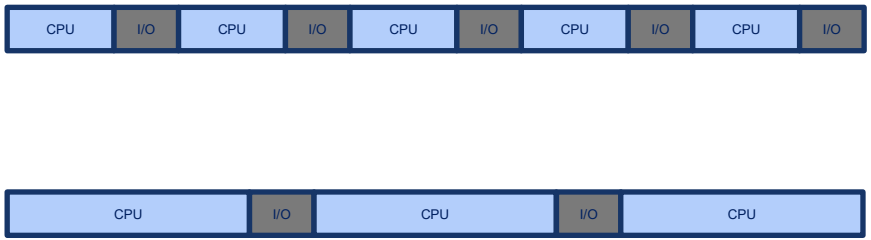
$$(2,\ 4) \xrightarrow{42} (5,\ 4) \xrightarrow{84} (5,\ 2)$$

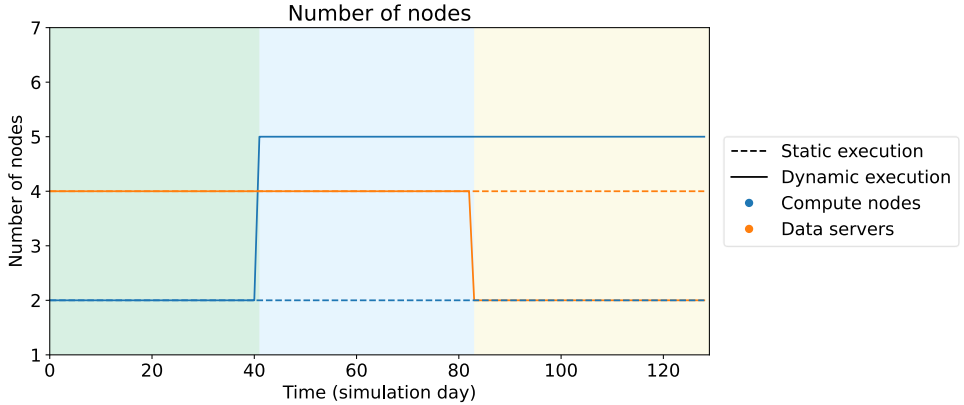


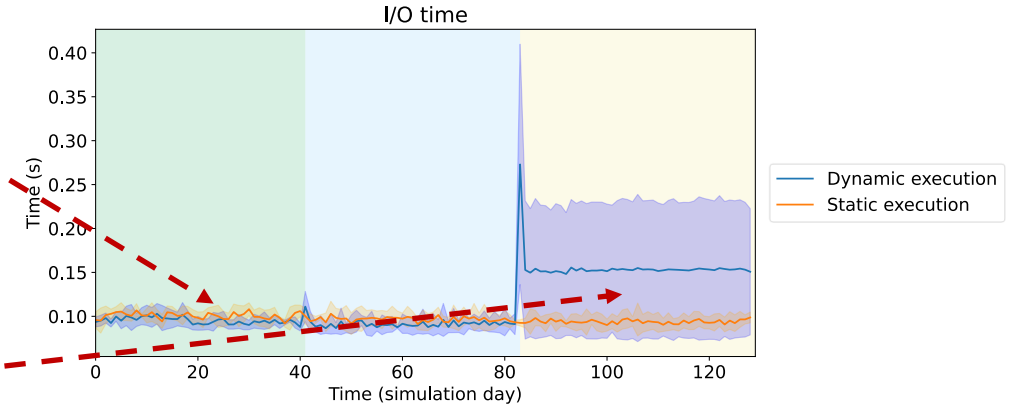
Evaluation

CPU vs I/O time

$$(2,\ 4) \xrightarrow{42} (5,\ 4) \xrightarrow{84} (5,\ 2)$$







Evaluation: balance CPU, I/O and OT

$$(2,\ 4) \xrightarrow{42} (5,\ 4) \xrightarrow{84} (5,\ 2)$$

	Static execution	Dynamic execution
Execution time	483 s	321 s
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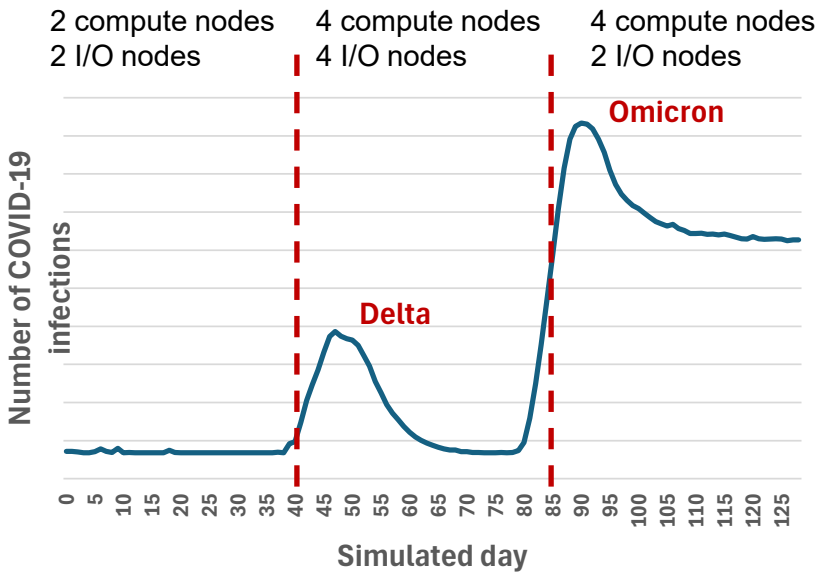
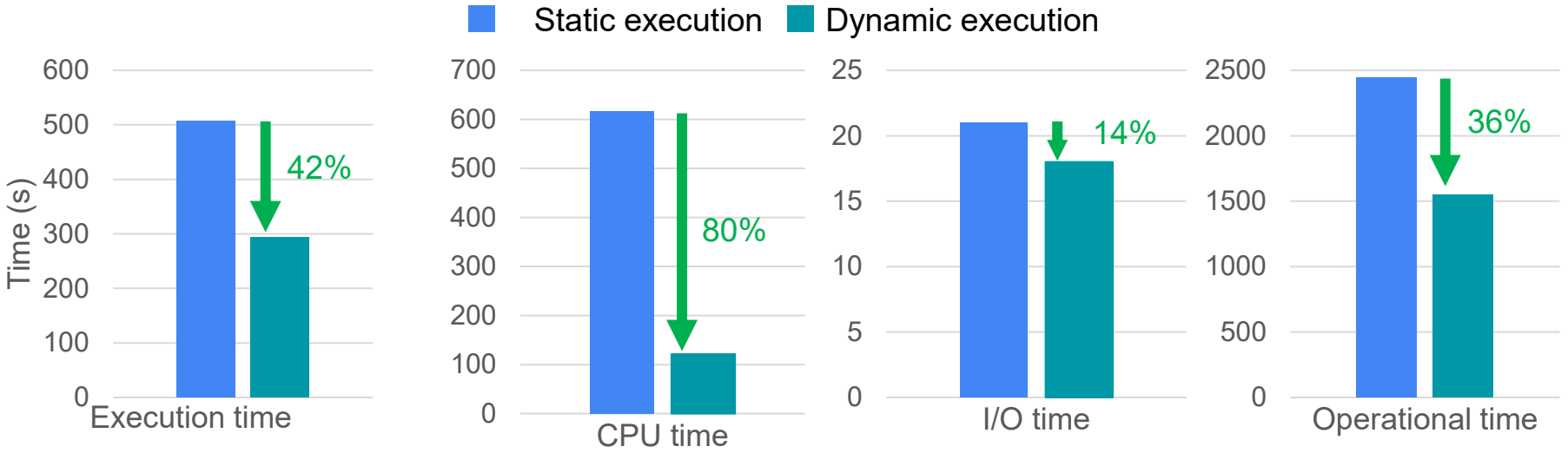


Evaluation


Static execution
Dynamic execution
Time (s)
600
500
400
300
200
100
0
42%
Execution time
700
600
500
400
300
200
100
0
80%
CPU time
25
20
15
10
5
0
14%
I/O time
2500
2000
1500
1000
500
0
36%
Operational time

Conclusion

- Optimizing applications with varying performance is a challenge.
- Dynamic resource management (CPU and I/O) adds additional dimensions to the optimization problem.
- There is significant room for improvement!
- The approach can be extended to other applications and file systems.

Credits (in order of appearance)

- Hercules. https://gitlab.arcos.inf.uc3m.es/admire/hercules
- EpiGraph. epigraph.uc3m.es
- FlexMPI. https://github.com/admire-eurohpc/ic
- Expand. https://www.uc3m.es/ss/Satellite/GruposInvestigacion/en/TextoDosColumnas/1371352039366/
- Sánchez-Checa, P., Sánchez-Gallegos, G., Garcia-Blas, J., Carretero, J., Singh, D.E. Comparative *Analysis of Algorithms for Malleability Decision-Making in Applications and File Systems*. **Euro-Par 2025: Parallel Processing Workshops**. 2025
- Sanchez-Checa, P., Garcia-Blas, J., Carretero, J., and Singh, D.E., *Combining Malleability and Distributed Control Mechanisms to Reduce I/O Contention*. **In High Performance Computing. ISC High Performance 2025 International Workshops**. 2025