RÉPUBLIQUE FRANÇAISE
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Pallas

A generic trace format for large HPC trace analysis

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Gaël Thomas & François Trahay

PROGRAMME DE RECHERCHE
NUMÉRIQUE POUR L'EXASCALE

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FRANCE 2030

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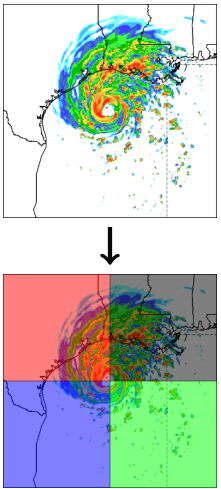
Introduction & Context

Large scale High Performance Computing (HPC)

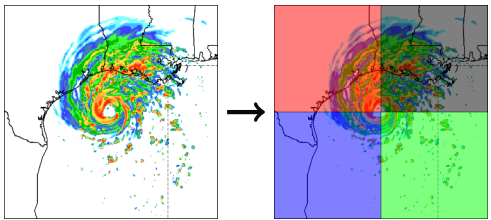
- Used for compute-intensive tasks (Weather forecast, AI training, nuclear simulations…)
- Extensive use of parallel programming:
  - Split the problem into **smaller problems**
  - Distribute the computations over **several processors**
  - Processors communicate their contribution **through the network**
- Various paradigms:
  - Multiple threads: OpenMP
  - Multiple processes: MPI
  - Task-based: StarPU



Performance issues in HPC

Performance scales with the number of cores...Right ?

- 4 processors $\rightarrow$ 3.8 times faster 🥳



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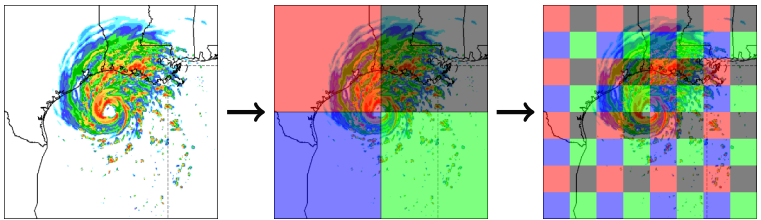
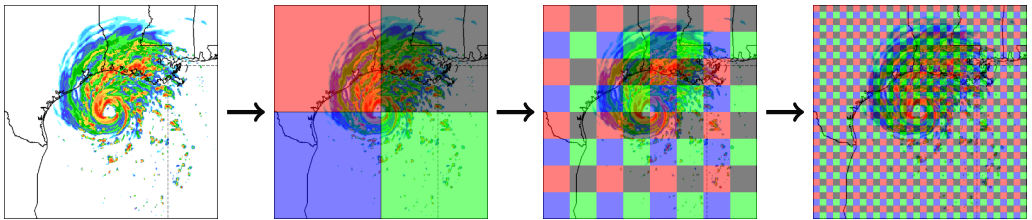
- 256 processors → 5.3 times faster 🤔



Performance issues in HPC

Performance scales with the number of cores...Right ?

- 4 processors → 3.8 times faster 🥳
- 256 processors → 5.3 times faster 🤔
- 1600 processors → 127 times **slower** 😭

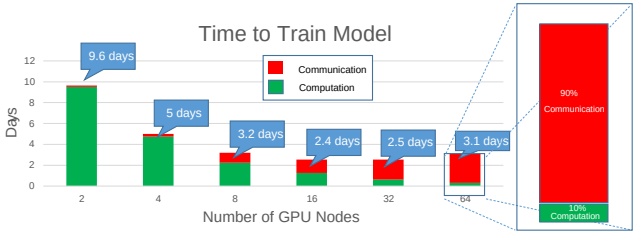


Performance issues sources

Scalability issues

Many different sources:

- Load-balancing (inactive threads)
- Concurrent access to resources
- Thread-to-thread communication



To scale/debug/optimize these apps, **we need performance analysis tools !**

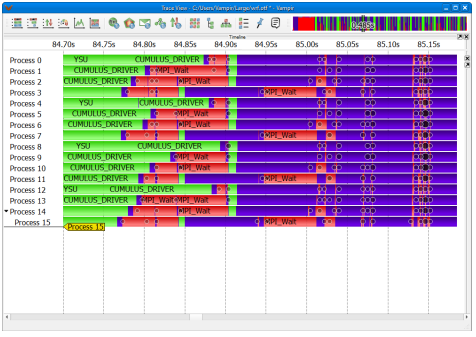
Traces & tracing tools

Traces

- Timeline of an execution
- Stores events (= POI) and metadata
  - Timestamps
  - Arguments (for function calls)
  - Callstack
  - ...

Tracing tools

Intercept known function calls (MPI, OMP, CUDA) and log them to create a trace



16-threads trace in Vampir

Traces & tracing tools

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Tracing tools

Intercept known function calls (MPI, OMP, CUDA) and log them to create a trace

32-threads trace in Vite

Traces: limitations

Scalability issues

- Trace size scales with number of threads and execution time
- Analysis time $\propto$ trace size
- Resources needed $\propto$ trace size

$\Longrightarrow$ bigger traces need supercomputers to be analyzed !

We need a new, more **scalable** trace format, with:

- low overhead during the execution
- fast & scalable analysis after the execution

Pallas

Pallas

Goal

Accelerating post-mortem analysis:

- **Structural**, **generic** trace format
- Automatic sequence detection

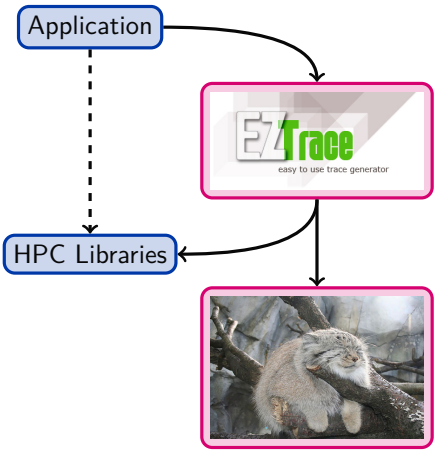
Software stack

EZTrace:

- Intercepts MPI/OMP/CUDA/other calls
- Builds OTF2 traces via OTF2 library

Pallas:

- Provides reading/writing API via C/C++ library
- Provides an OTF2 writing API



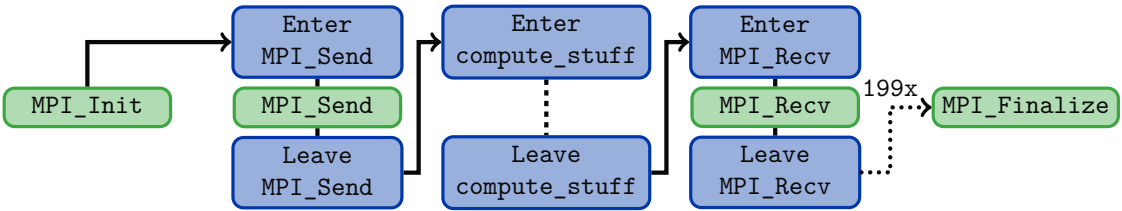
Example: Tracing with EZTrace

EZTrace

Intercepted functions:

- Enter and Leave events = scope
- Punctual event (*e.g.* message sent)

```
MPI_Init(...)
for _ in range(200):
  MPI_Send(...)
  compute_stuff(...)
  MPI_Recv(...)
MPI_Finalize(...)
```



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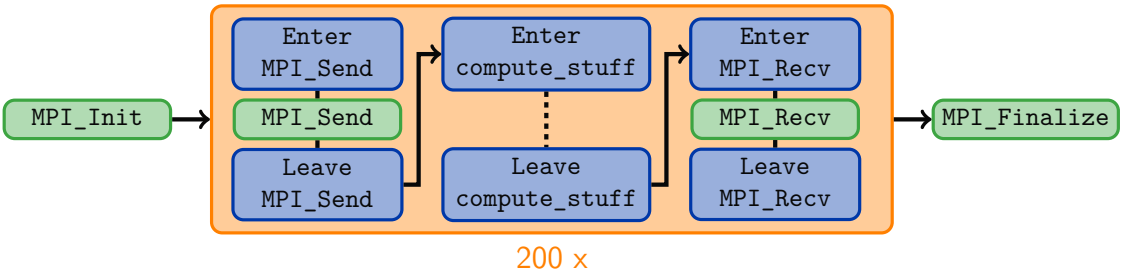

Structure detection

Pallas Trace Format

- Everything is a **generic token**
- Specific information is stored in a **grammar**
- Enter and Leave events define Sequences
- Repetitions of tokens create Loops

Example: Grammar

- E_0 : `MPI_Init`

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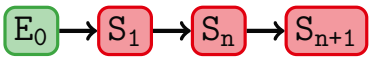

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- S_{n+1} : $E_pE_qE_r$ (`MPI_Recv`)

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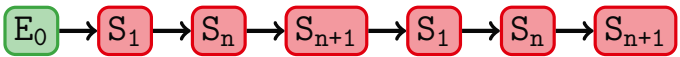

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- L_m : $2 \times S_1S_nS_{n+1}$

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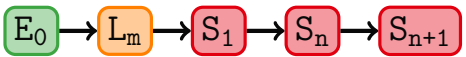

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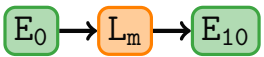

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- S_n : $E_4 \ldots E_k$ (`compute_stuff`)
- ...
- S_{n+1} : $E_pE_qE_r$ (`MPI_Recv`)
- L_m : $200 \times S_1S_nS_{n+1}$
- E_{10} : `MPI_Finalize`

Trace format

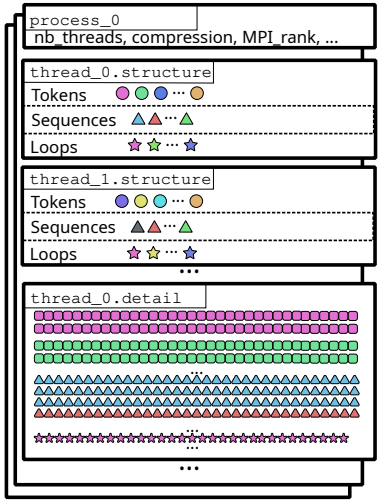
Structure built for HPC

One folder / thread → allows 1k+ threads to write simultaneously on NFS

Smart data storage & retrieval

Data is segregated between:

- Program structure (MB)
  - Execution information & trace metadata
  - Grammar
  - Events / Sequences statistics
- Timestamps and durations (GB/TB)
  - Compressible
  - Loaded on-the-fly



Post-mortem analysis tools

pallas_contention

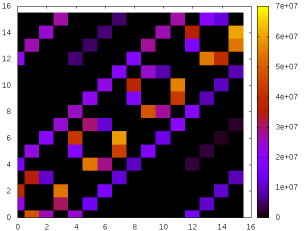
- Compute a contention score based on sequence statistics
- Only needs the program structure

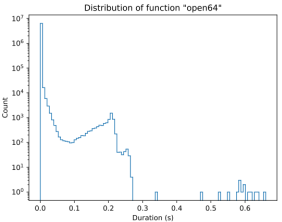
pallas_comm_matrix

- Creates a communication matrix based on the grammar
- Only needs the program structure

pallas_histogram

- Creates a histogram of the distribution of a function's duration
- Only needs the sequence's durations





Benchmarks and Evaluations

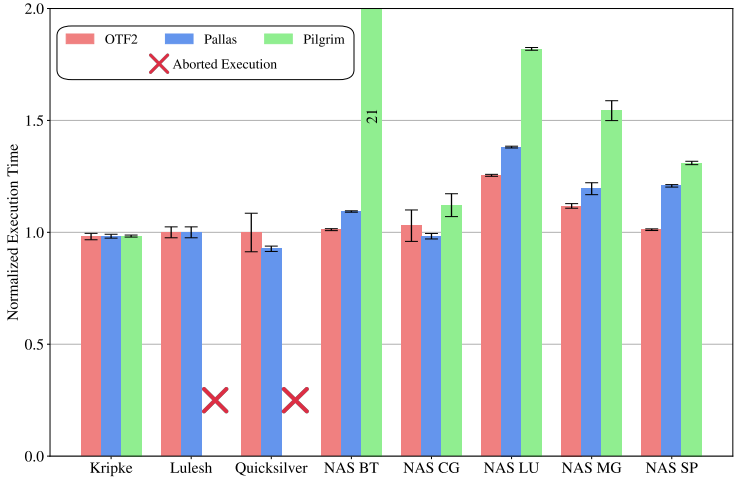
Experimental parameters

- Platform: **Jean-Zay** supercomputer
  - Scalar partition: 2x20 cores, 192 GiB RAM
    - Execution using 4096 MPI ranks
  - GPU partition: 2x20 cores, 192 GiB RAM, 4 NVIDIA V100 GPUs
    - Execution using 128 MPI ranks
- We compare
  - `Vanilla`: no tracing
  - `OTF2`: tracing with EZTrace in OTF2
  - `Pallas`: tracing with EZTrace in Pallas
  - `Pilgrim`: tracing with Pilgrim
- Applications: Lulesh, Quicksilver, Kripke, NAS Parallel Benchmark
  - Tracing the MPI functions

Overhead

Key points

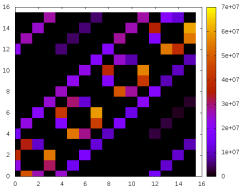
- **Lower is better !**
- Pallas adds very little overhead compared to OTF2
- Pilgrim struggles when tracing complex applications

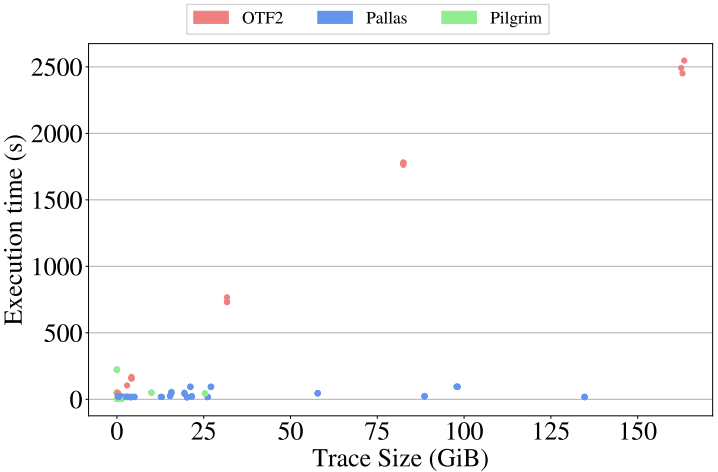


Analysis speed: Communication Matrix

Key points

- Pilgrim/Pallas $\lll$ OTF2
- Pilgrim/Pallas $\rightarrow$ scalable

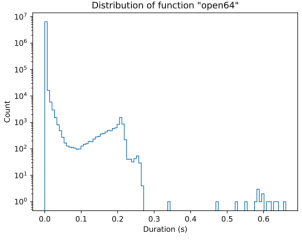


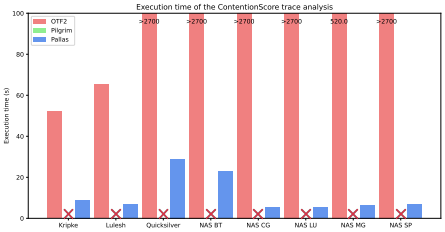


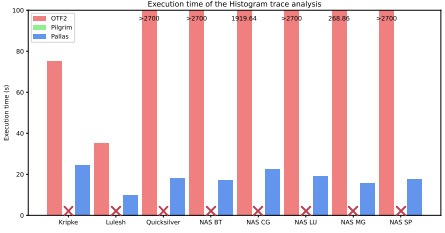
Analysis speed: Contention & Histogram

Key points

- Pilgrim has no API for analysis
- Pallas → scalable, almost constant
- OTF2 needs to read a lot more data







Case study: Distributed training of a ML model

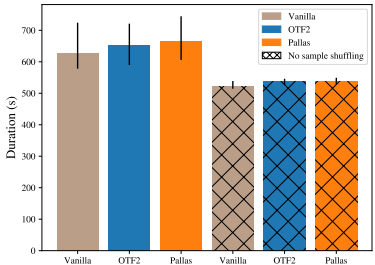
Resnet50

- 5 epochs over the ImageNet dataset over 128 GPUs
- Known issue: sample shuffling causes I/O contention
- Tracing with OTF2 & Pallas
  - MPI, PosixIO, some Python functions

Results

- Vanilla has significant variation for its duration
- Pallas' time to solution is significatively shorter

	EZTrace/OTF2	EZTrace/Pallas
Trace Size	6.1GiB	1.4GiB
Total Time	1366s	160s



Conclusion

Conclusion

Current features

- ✓ Low Overhead
- ✓ Structure detection
  - ✓ Leveraged in quick and scalable analyses
- ✓ Efficient storage
- ✓ Efficient compression
- ✓ On demand-trace loading and exploration
- ✓ Python API and basic trace visualization

Future endeavours

- Trace visualization:
  - Open a 50 GiB trace instantaneously
  - Displaying 1k threads on an average screen
- Improve trace analysis API (Python, R)
- Improve tracing performance

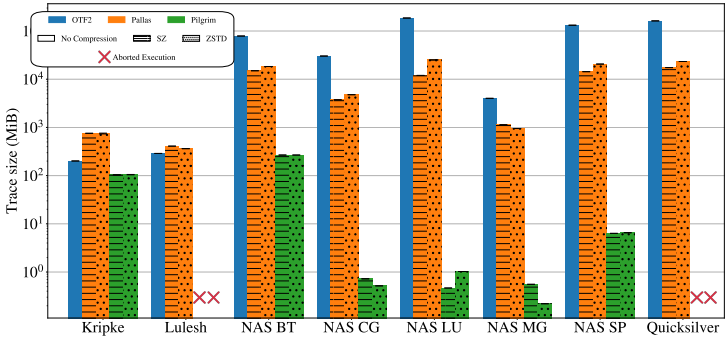
Come check us out at:
gitlab.inria.fr/pallas/pallas

Appendix

Trace size & compression

Key points

- **Lower is better∗ !**
- OTF2 $\approx 10 \cdot$ Pilgrim
- Pilgrim collects less information than EZTrace
- Pigrim **compresses all the timestamps together**.



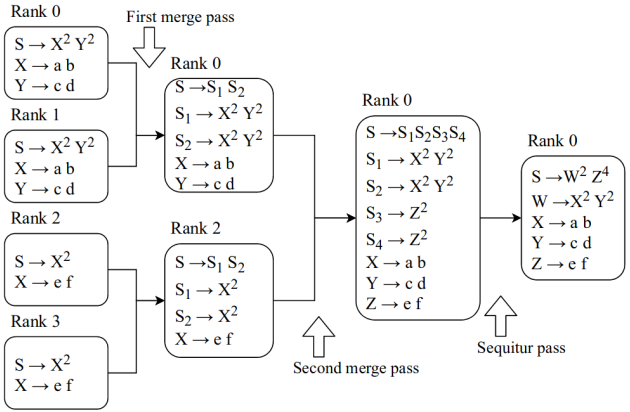
Timestamp compression & encoding

Durations are similar → easily compressible
Different storage options:

- No timestamps (Structure only)
- Encoding:
  - Removed leading 0s
  - Replace leading 0s (as presented before)
- Compression:
  - ZSTD
  - SZ
  - ZFP
  - Bin-based (similar to QSDG)
  - Histogram-based (same thing but Gaussian distribution)

} Lossy compression

(Pilgrim) Inter-trace compression



Using ncurses