Lecture 10: Performance Tools

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Announcements

- Quiz 1 has been posted
- Deadline: October 1, 11:59 pm AoE
- Department seminar tomorrow at 11:00 am
  - Zoom link forwarded by e-mail

Performance analysis

- Parallel performance of a program might not be what the developer expects
- How do we find performance bottlenecks?
- Two parts to performance analysis: measurement and analysis/visualization
- Simplest tool: timers in the code and printf

Using timers

```
double start, end;
double phase1, phase2, phase3;

start = MPI_Wtime();
 ... phase1 code ...
end = MPI_Wtime();
phase1 = end - start;

start = MPI_Wtime();
 ... phase2 ...
end = MPI_Wtime();
phase2 = end - start;

start = MPI_Wtime();
 ... phase3 ...
end = MPI_Wtime();
phase3 = end - start;
```

Using timers

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double start, end;
double phase1, phase2, phase3;

start = MPI_Wtime();
 ... phase1 code ...
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start = MPI_Wtime();
 ... phase3 ...
end = MPI_Wtime();
phase3 = end - start;
```

Phase 1 took 2.45 s

Phase 2 took 11.79 s

Phase 3 took 4.37 s

Performance tools

- Tracing tools
  - Capture entire execution trace
- Profiling tools
  - Provide aggregated information
  - Typically use statistical sampling
- Many tools can do both

Metrics recorded

- Counts of function invocations
- Time spent in code
- Number of bytes sent
- Hardware counters
- To fix performance problems — we need to connect metrics to source code

Tracing tools

- Record all the events in the program with timestamps
- Events: function calls, MPI events, etc.

Vampir visualization: https://hpc.llnl.gov/software/development-environment-software/vampir-vampir-server

Tracing tools

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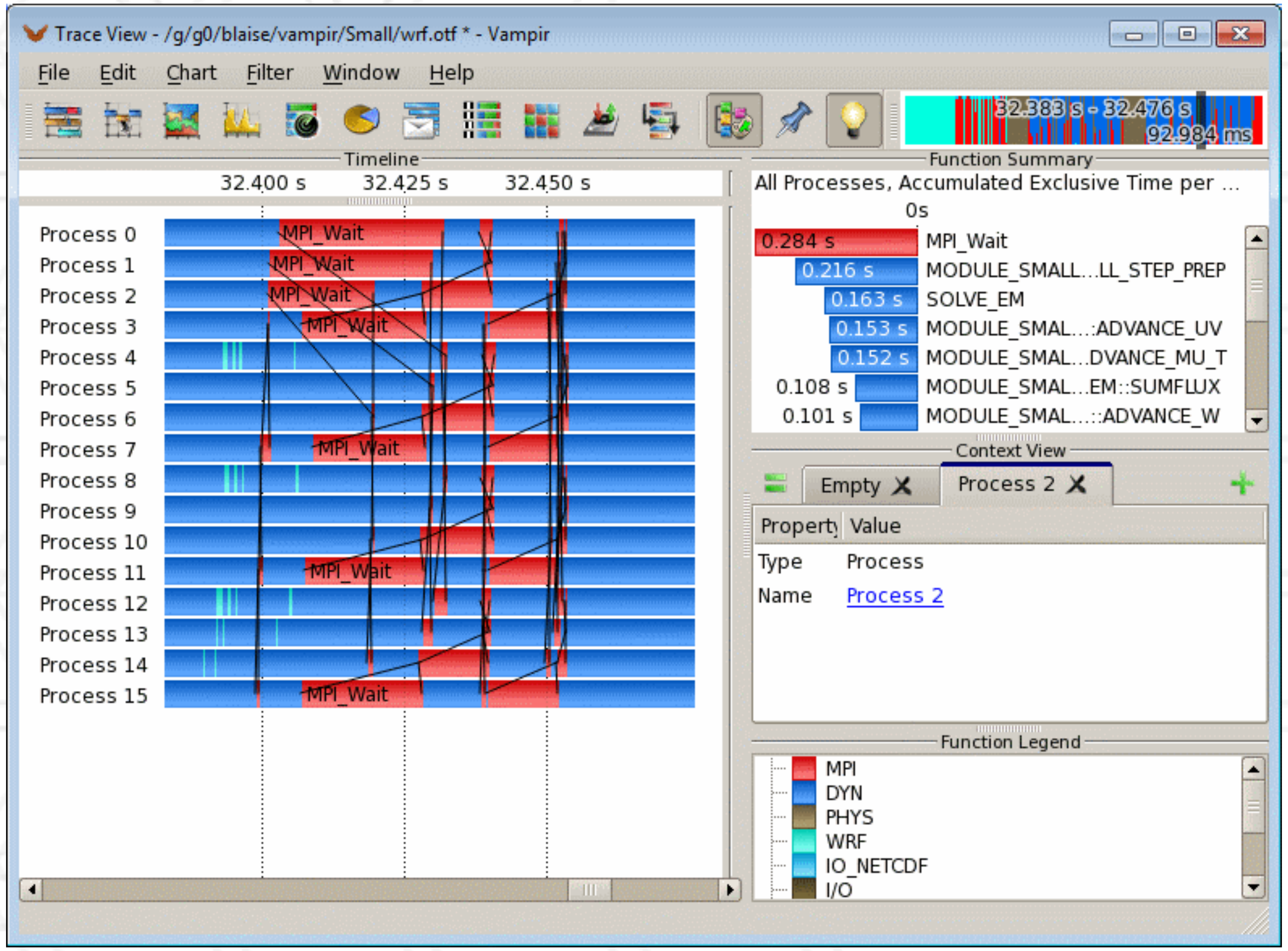

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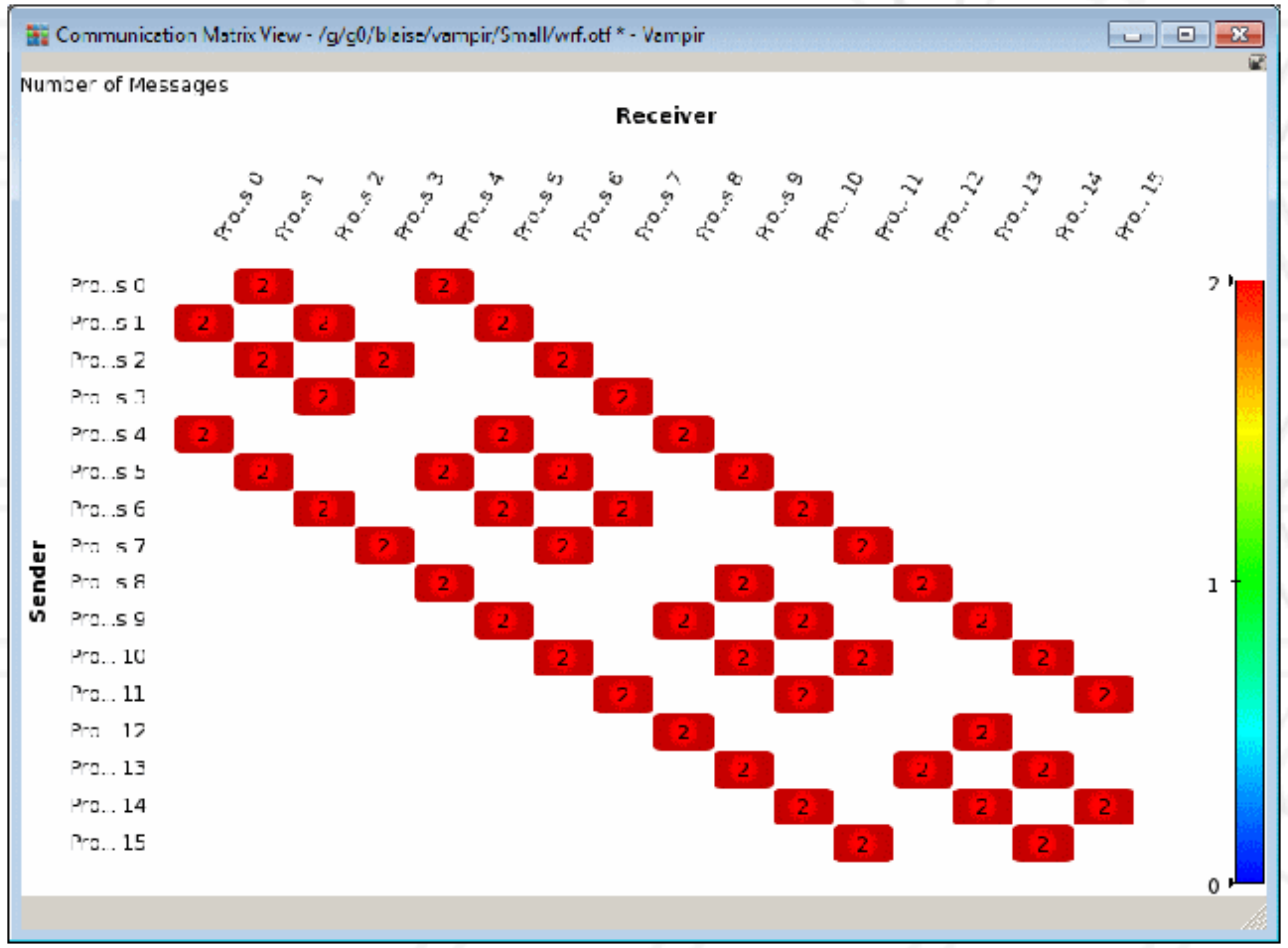

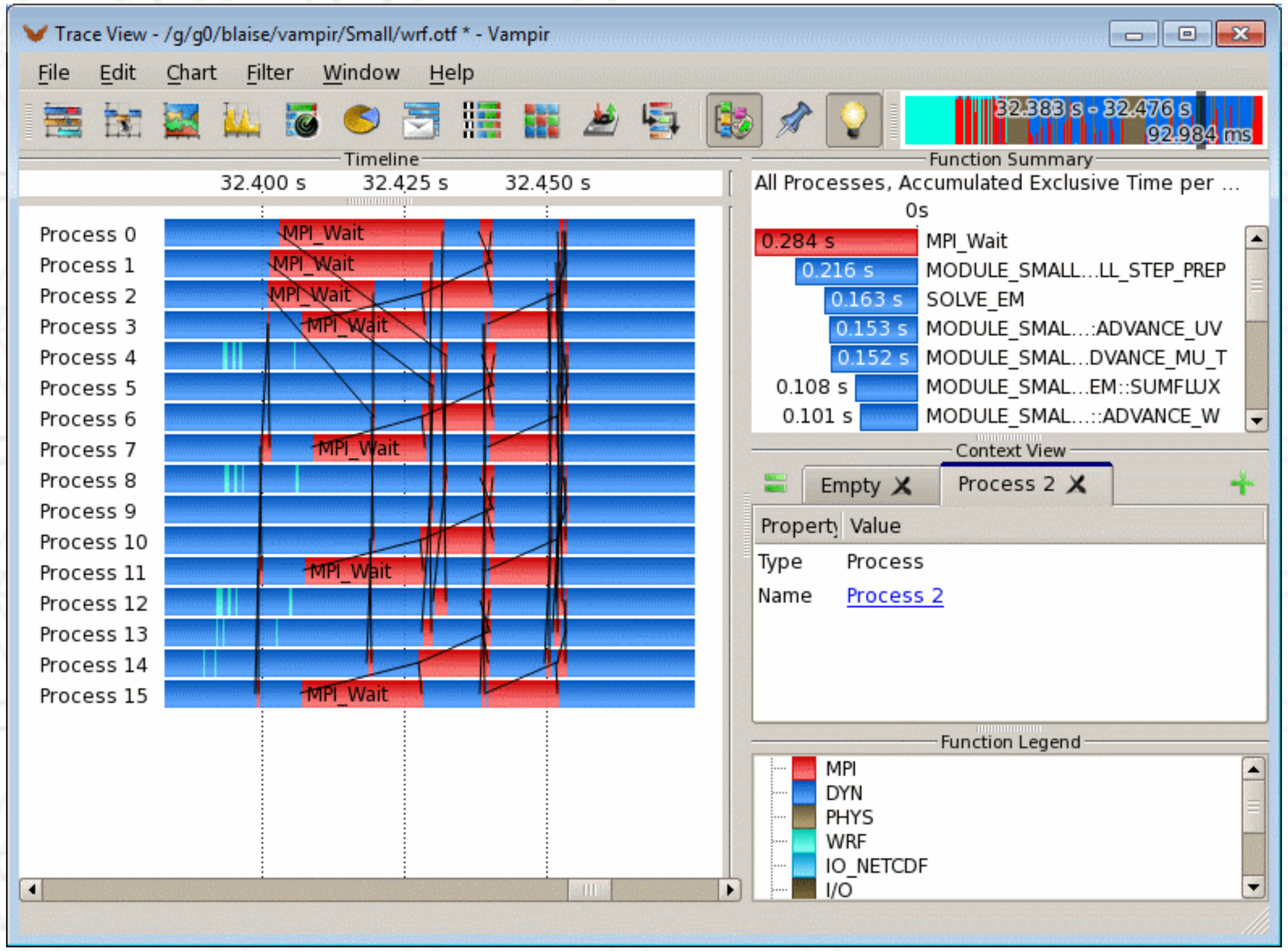

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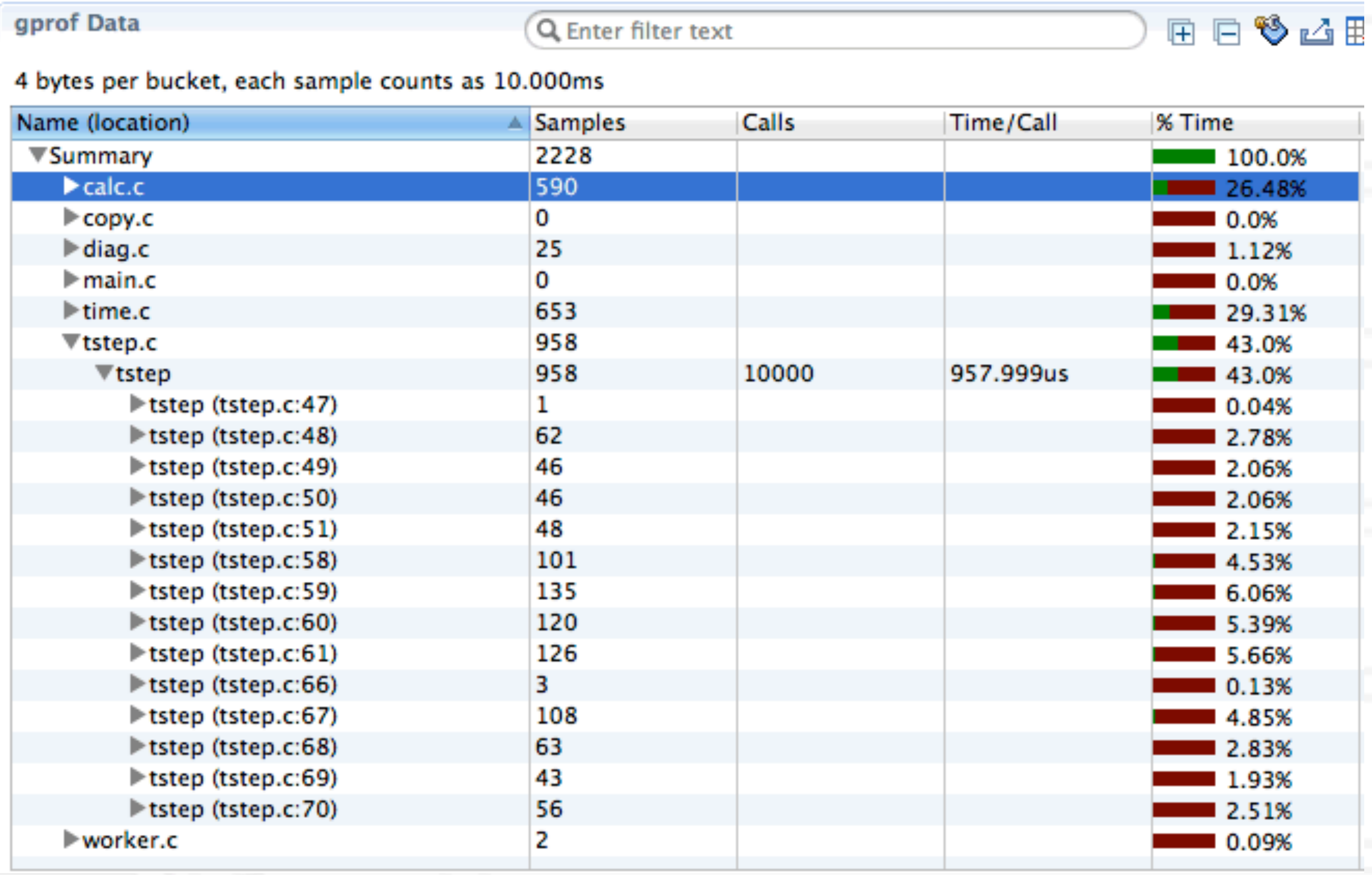
Examples of tracing tools

- VampirTrace
- Score-P
- TAU
- Projections
- HPCToolkit

Profiling tools

- Ignore the specific times at which events occurred
- Provide aggregate information about different parts of the code
- Examples:
  - Gprof, perf
  - mpiP
  - HPCToolkit, caliper
- Python tools: cprofile, pyinstrument, scalene


gprof Data

Enter filter text

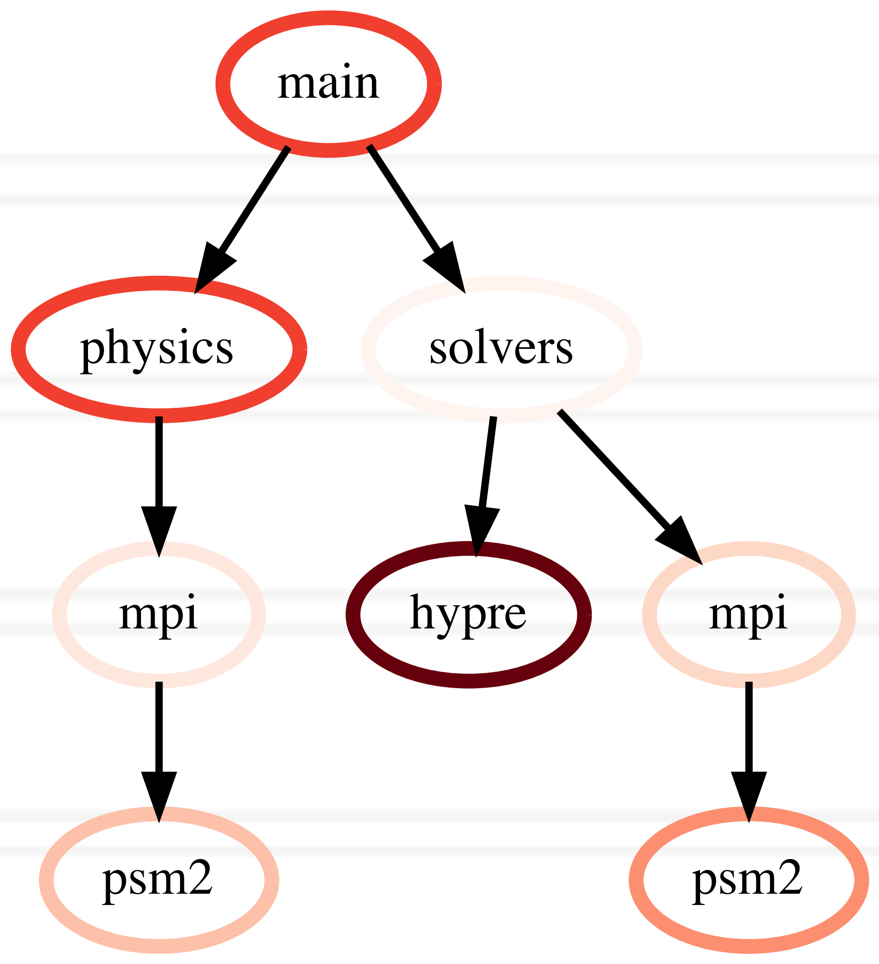
4 bytes per bucket, each sample counts as 10.000ms

Name (location)	Samples	Calls	Time/Call	% Time
Summary	2228			100.0%
calc.c	590			26.48%
copy.c	0			0.0%
diag.c	25			1.12%
main.c	0			0.0%
time.c	653			29.31%
tstep.c	958			43.0%
tstep	958	10000	957.999us	43.0%
tstep (tstep.c:47)	1			0.04%
tstep (tstep.c:48)	62			2.78%
tstep (tstep.c:49)	46			2.06%
tstep (tstep.c:50)	46			2.06%
tstep (tstep.c:51)	48			2.15%
tstep (tstep.c:58)	101			4.53%
tstep (tstep.c:59)	135			6.06%
tstep (tstep.c:60)	120			5.39%
tstep (tstep.c:61)	126			5.66%
tstep (tstep.c:66)	3			0.13%
tstep (tstep.c:67)	108			4.85%
tstep (tstep.c:68)	63			2.83%
tstep (tstep.c:69)	43			1.93%
tstep (tstep.c:70)	56			2.51%
worker.c	2			0.09%

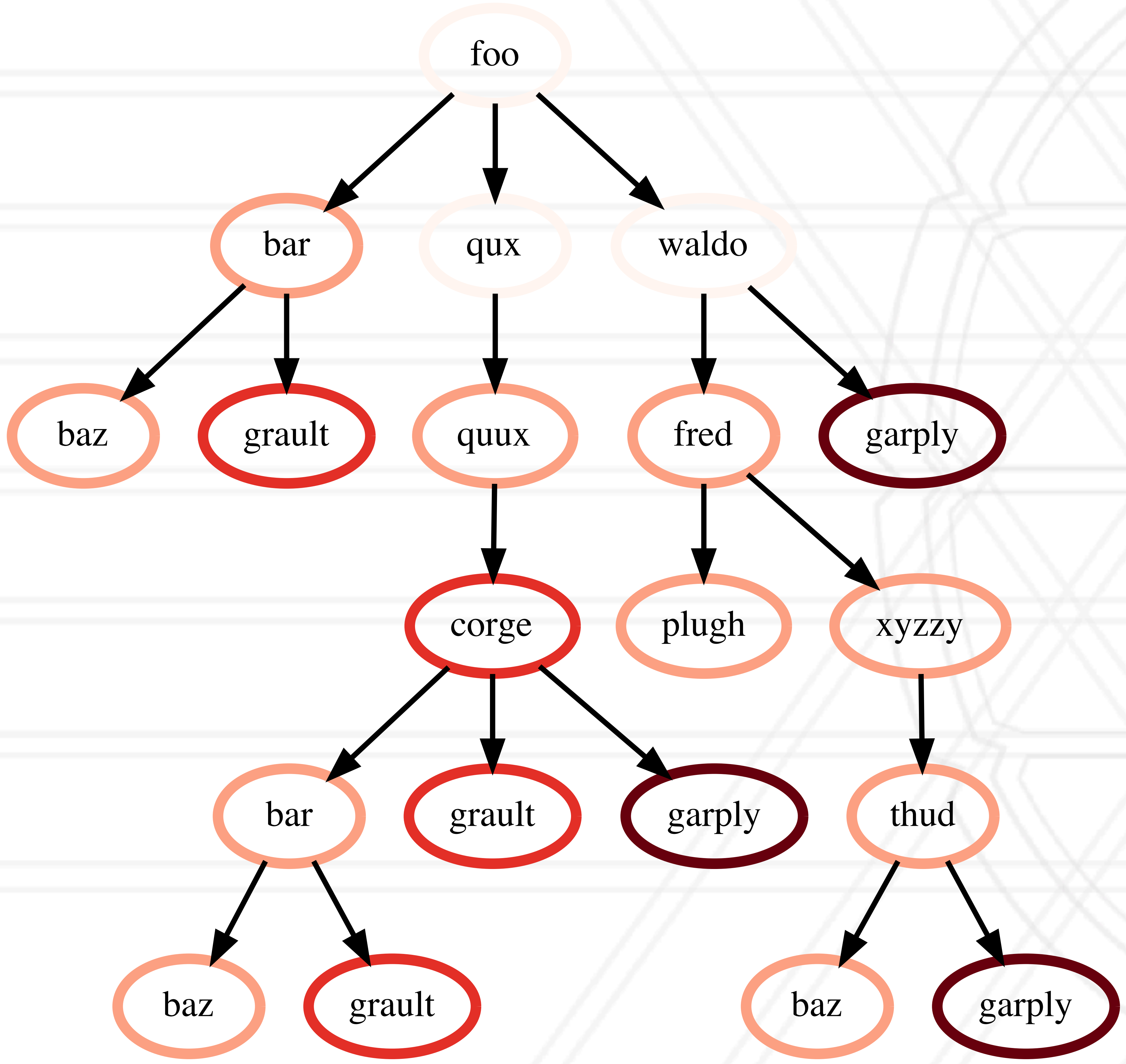
Gprof data in hpctView

Calling contexts, trees, and graphs

- Calling context or call path: Sequence of function invocations leading to the current sample
- Calling context tree (CCT): dynamic prefix tree of all call paths in an execution
- Call graph: merge nodes in a CCT with the same name into a single node but keep caller-callee relationships as arcs



Calling context trees, call graphs, …



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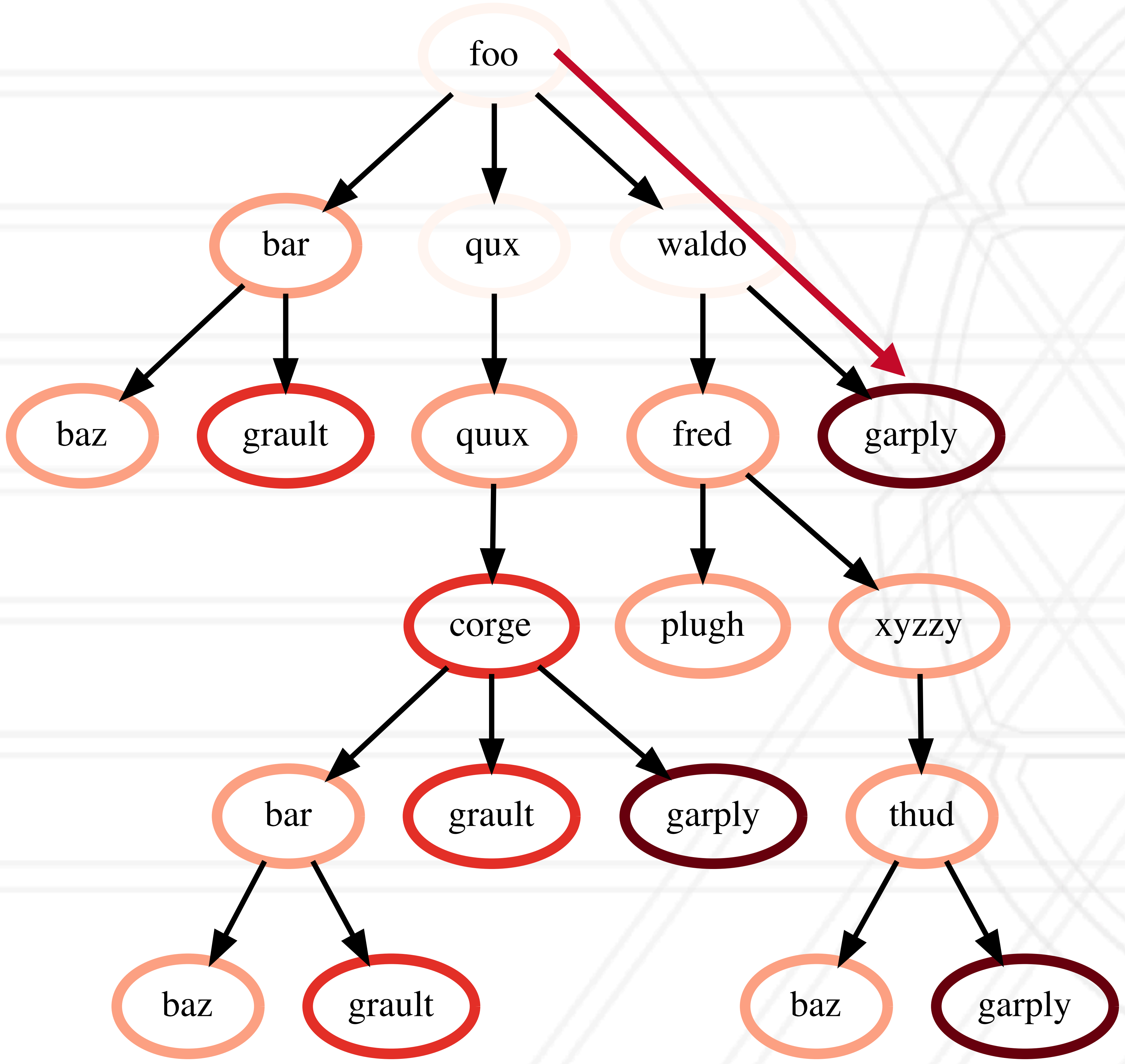

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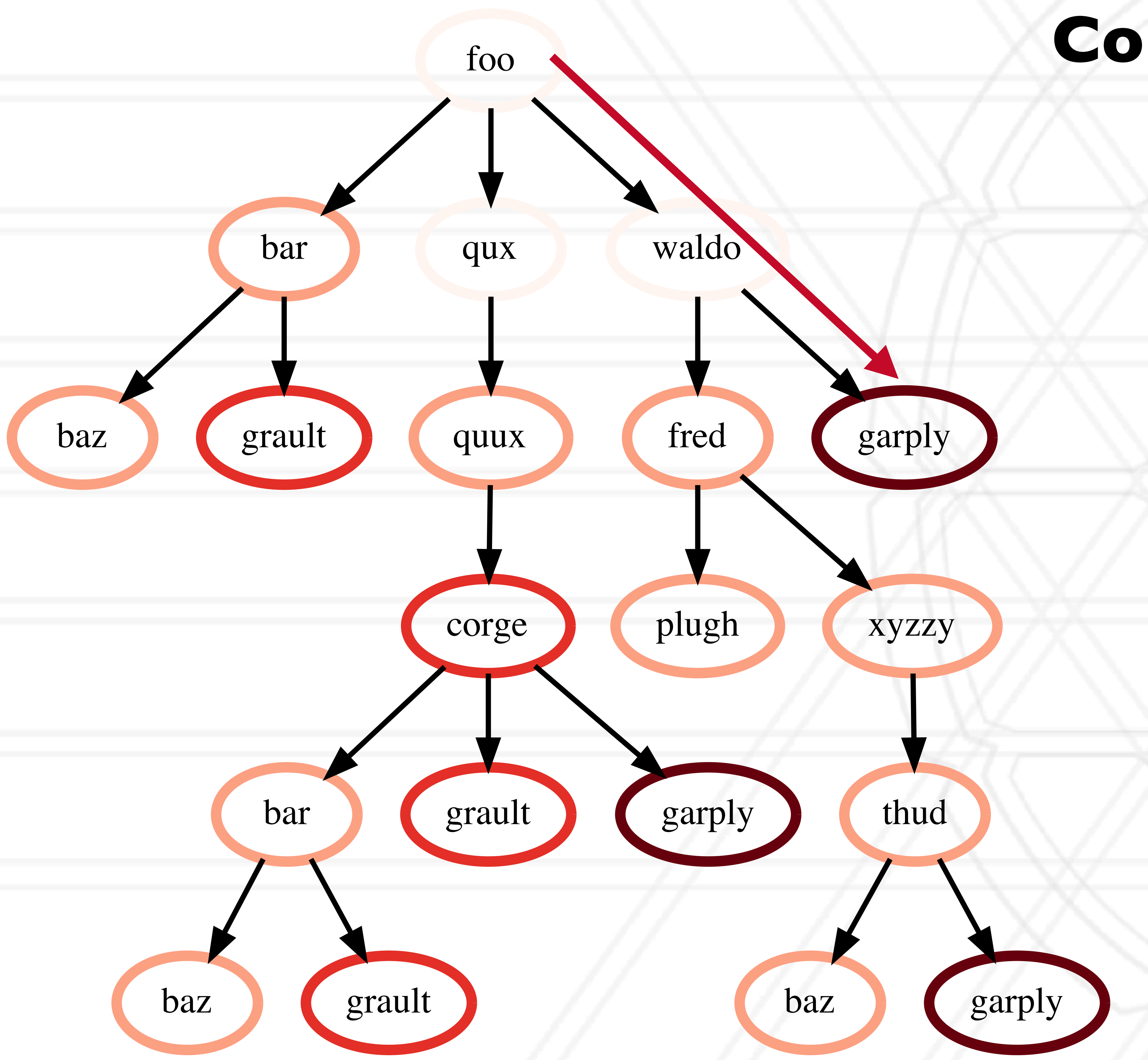
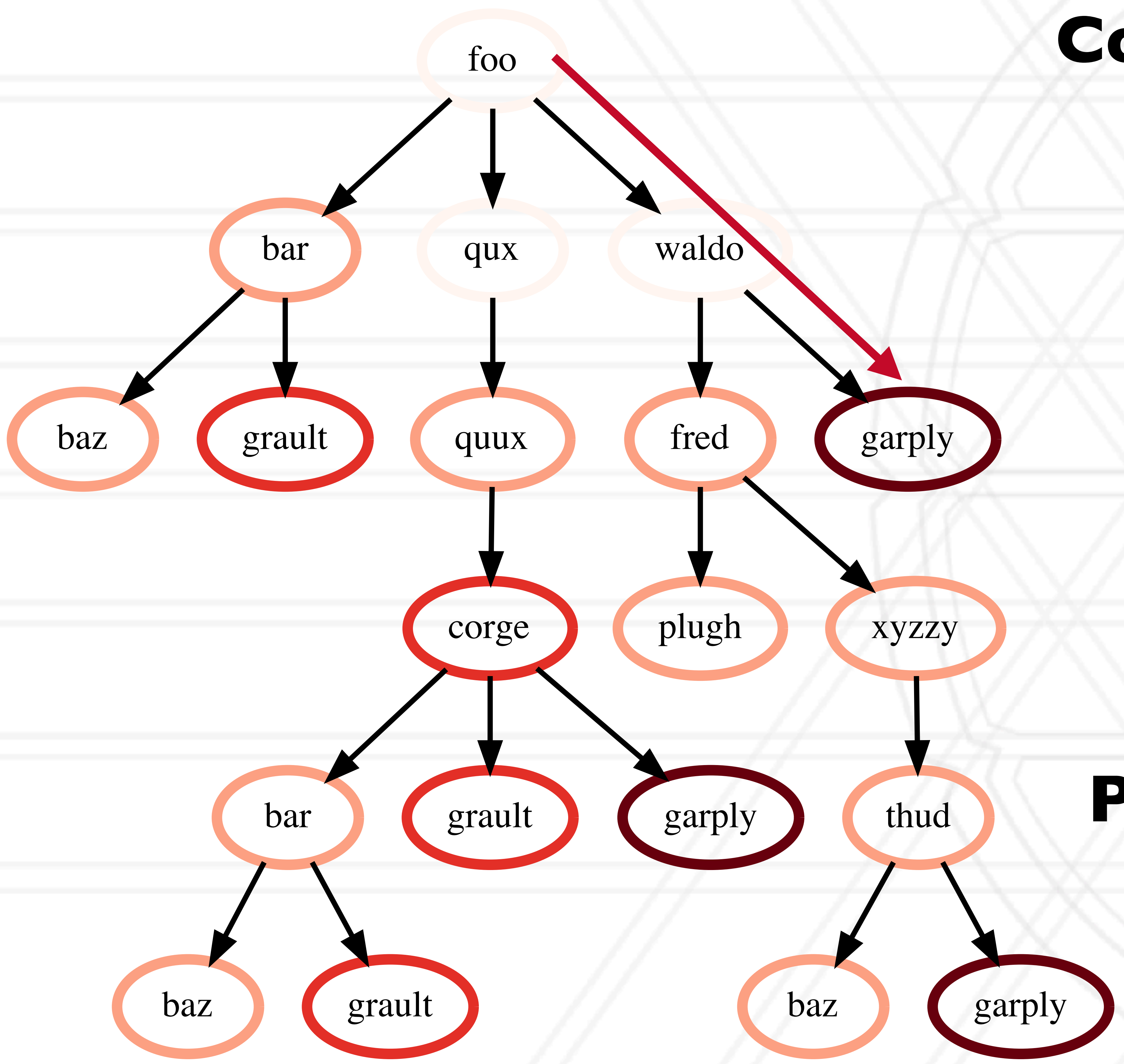


Calling context tree (CCT)

Contextual information

```
File
Line number
Function name
Callpath
Load module
Process ID
Thread ID
```

Calling context trees, call graphs, …



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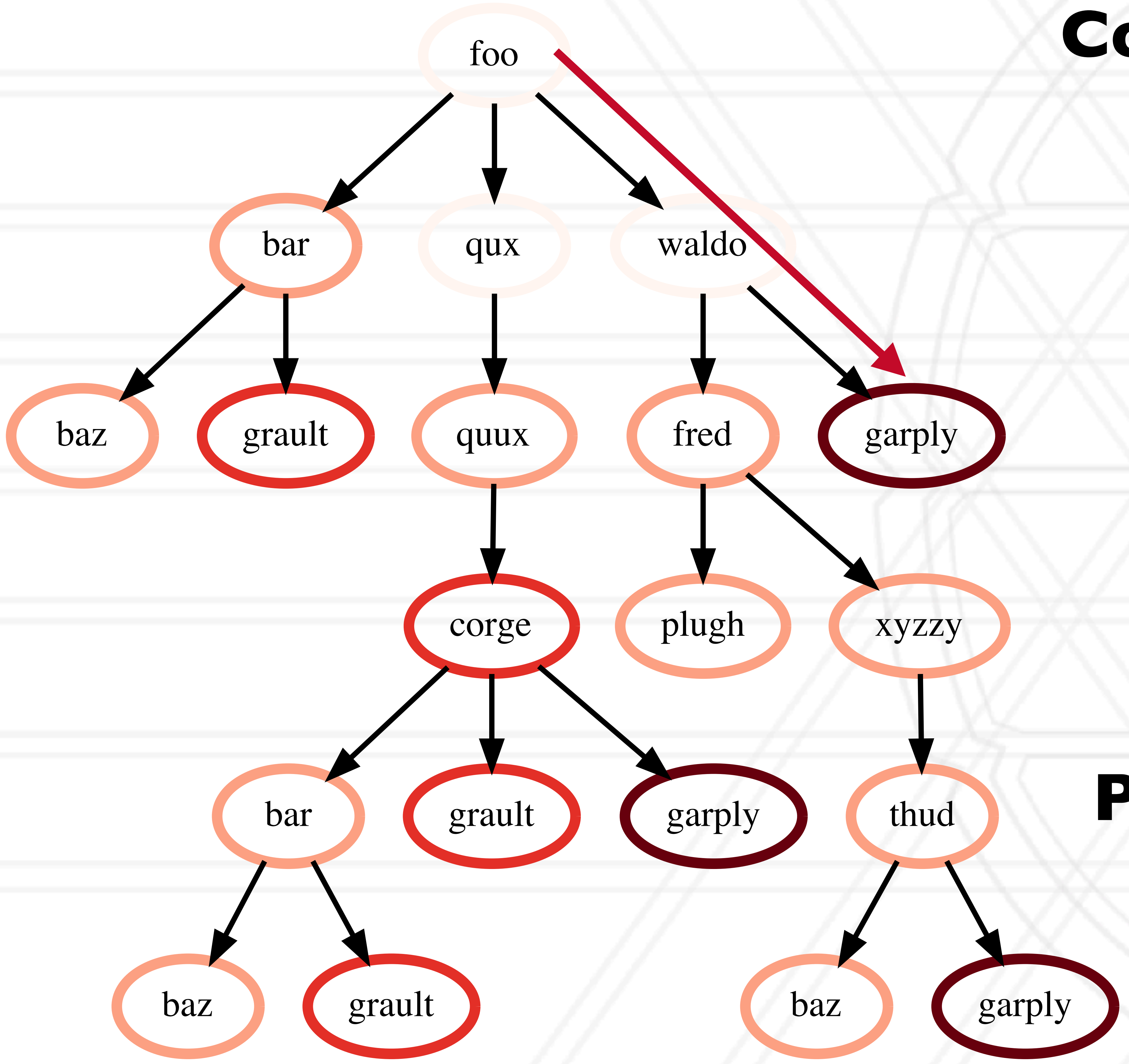
Performance Metrics

Time
Flops
Cache misses

Calling context trees, call graphs, …



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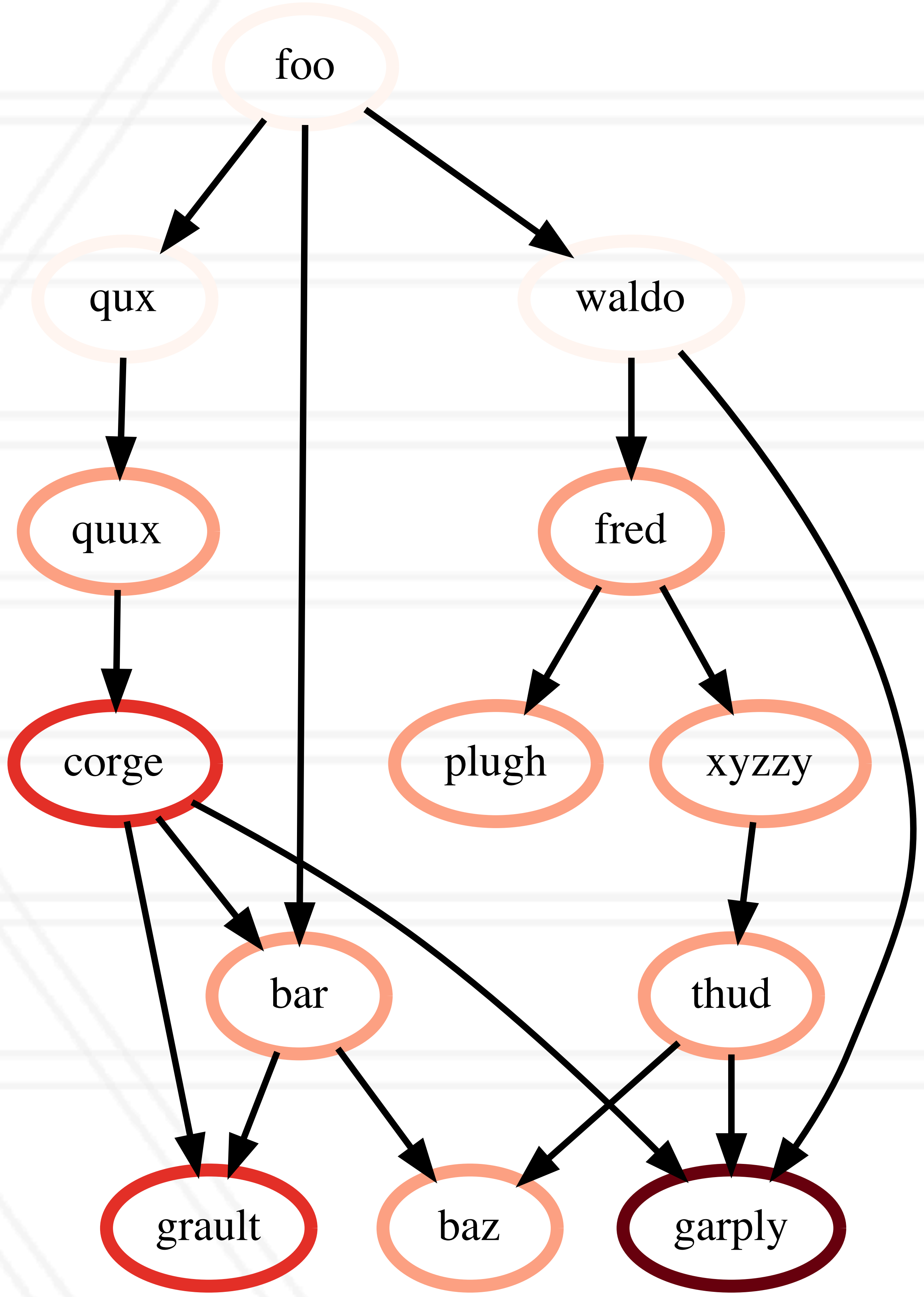
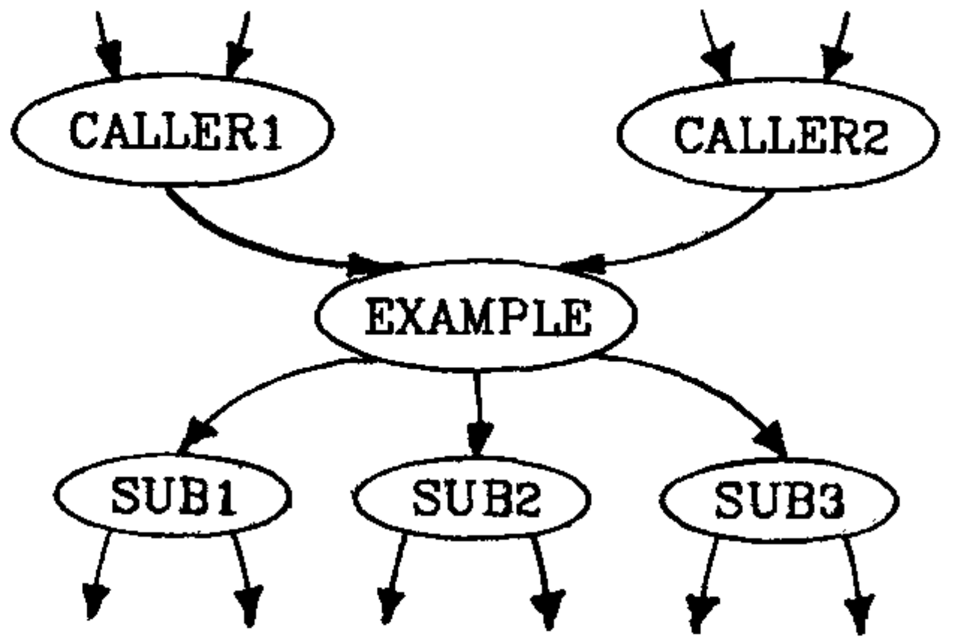
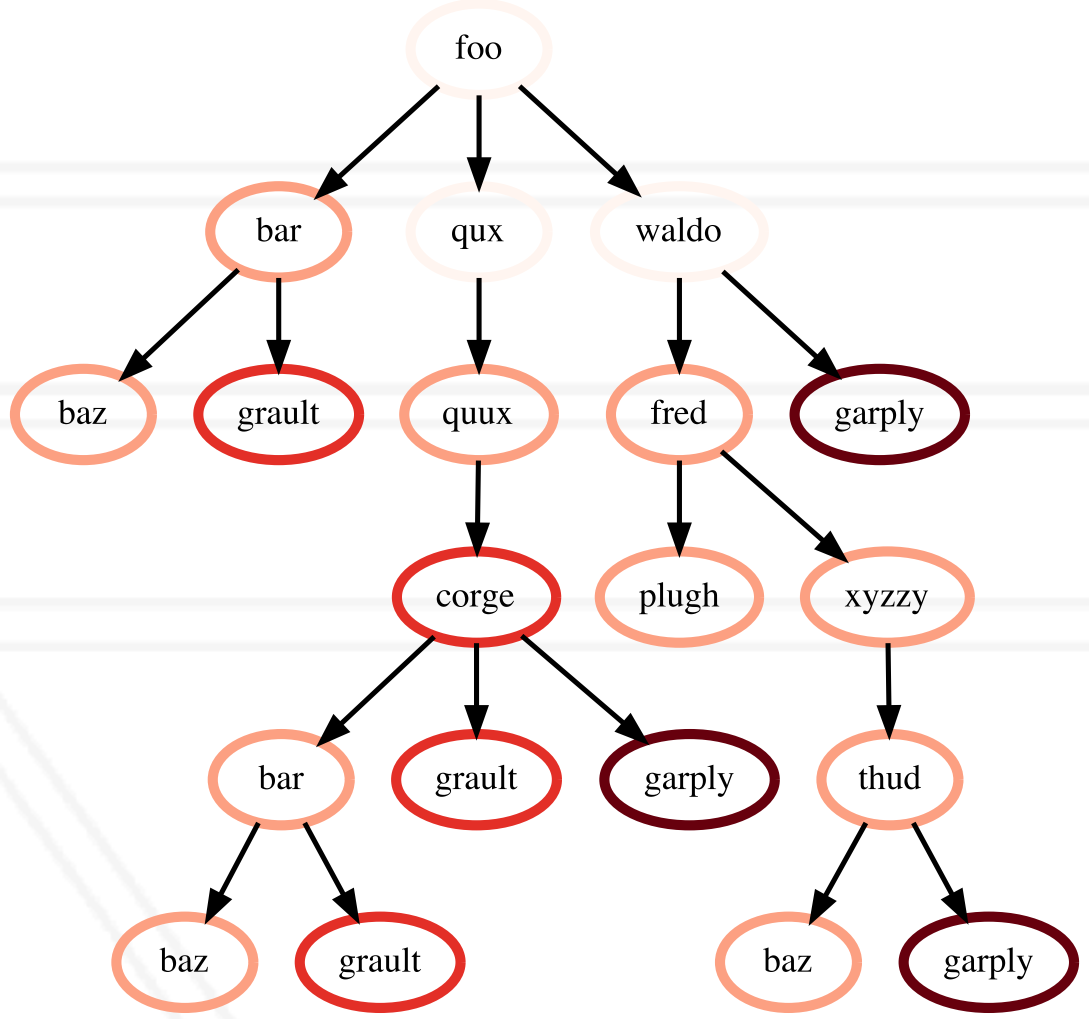


Call graph

Output of profiling tools

- Flat profile: Listing of all functions with counts and execution times
- Call graph profile
- Calling context tree





Hatchet

- Hatchet enables programmatic analysis of parallel profiles
- Leverages pandas which supports multi-dimensional tabular datasets
- Create a structured index to enable indexing pandas dataframes by nodes in a graph
- A set of operators to filter, prune and/or aggregate structured data

https://hatchet.readthedocs.io/en/latest/

Pandas and dataframes

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  - Supports many operations borrowed from SQL databases

Columns

Rows

	node	name	time (inc)	time
0	{'name': 'main'}	main	200.0	10.0
1	{'name': 'physics'}	physics	60.0	40.0
2	{'name': 'mpi'}	mpi	20.0	5.0
3	{'name': 'psm2'}	psm2	15.0	30.0
4	{'name': 'solvers'}	solvers	100.0	10.0
5	{'name': 'hypre'}	hypre	65.0	30.0
6	{'name': 'mpi'}	mpi	35.0	20.0
7	{'name': 'psm2'}	psm2	25.0	60.0

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Pandas and dataframes

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- Dataframe: two-dimensional tabular data structure
  - Supports many operations borrowed from SQL databases
- MultiIndex enables working with high-dimensional data in a 2D data structure

Index — Columns — Rows

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Central data structure: a *GraphFrame*

- Consists of a structured index graph object and a pandas dataframe
- Graph stores caller-callee relationships
- Dataframe stores all numerical and categorical data

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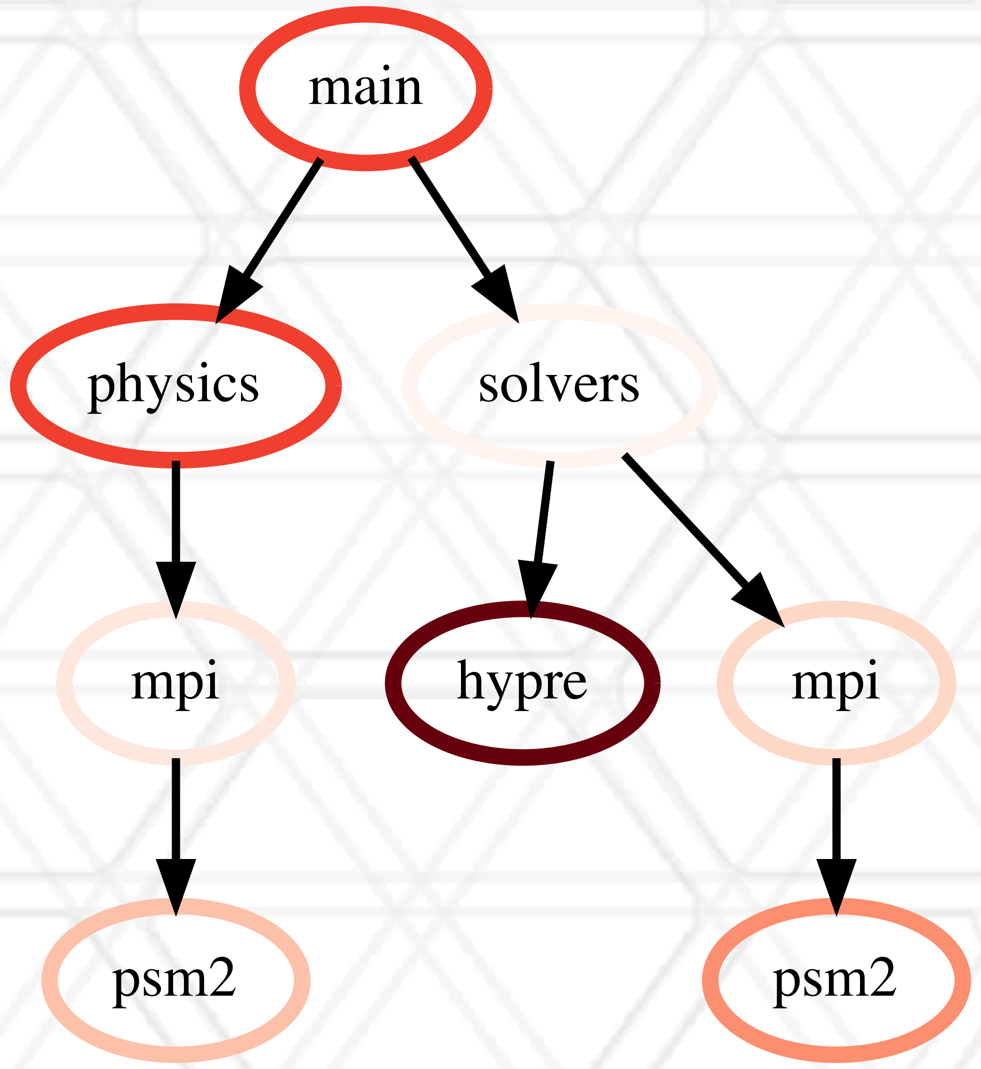

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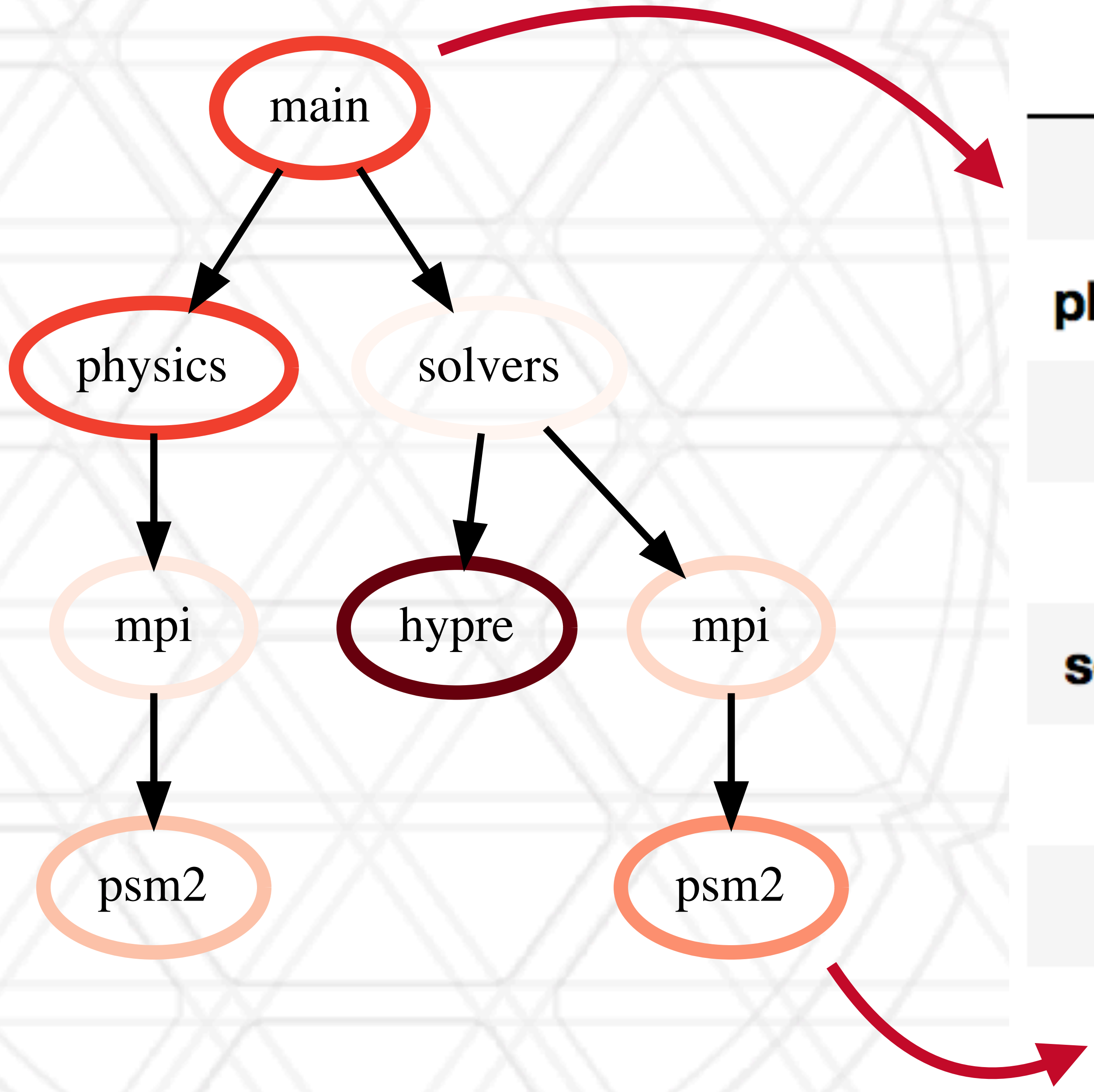

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Dataframe operation: filter

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filtered_gf = gf.filter(lambda x: x['time'] > 10.0)
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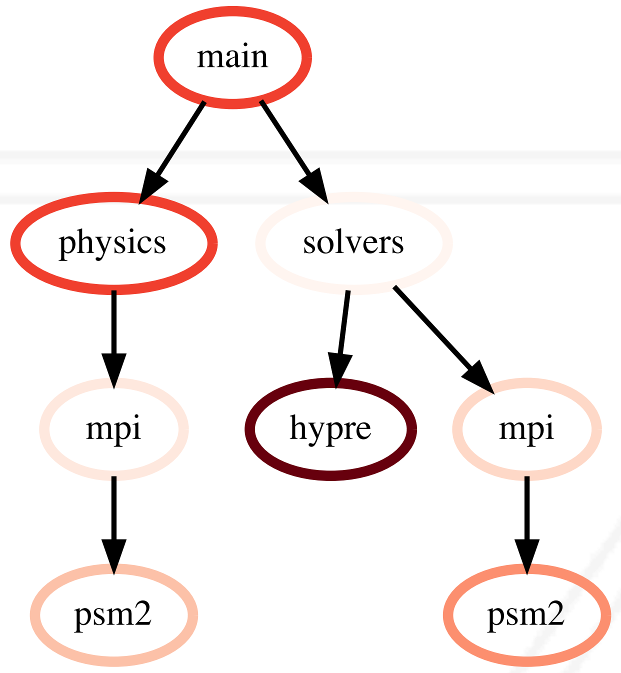

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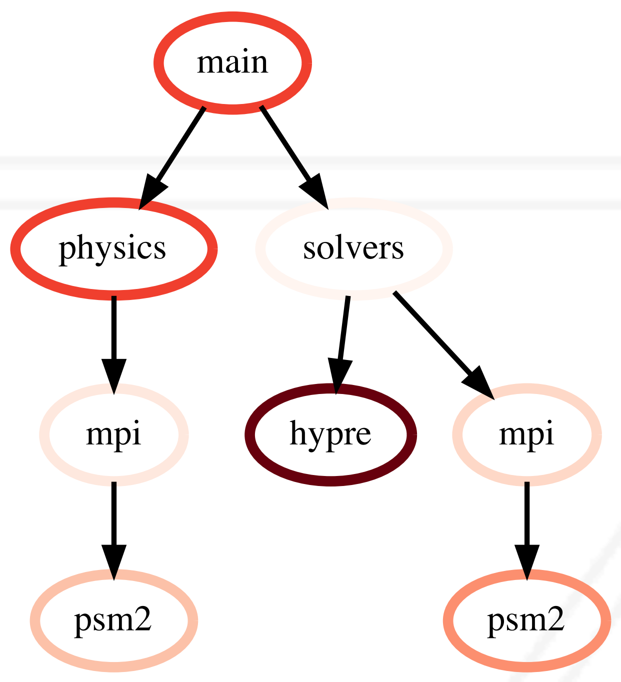

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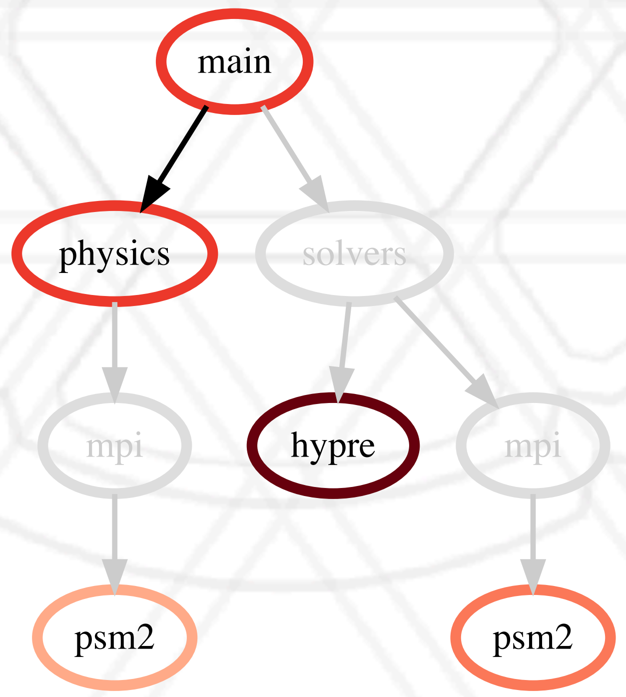

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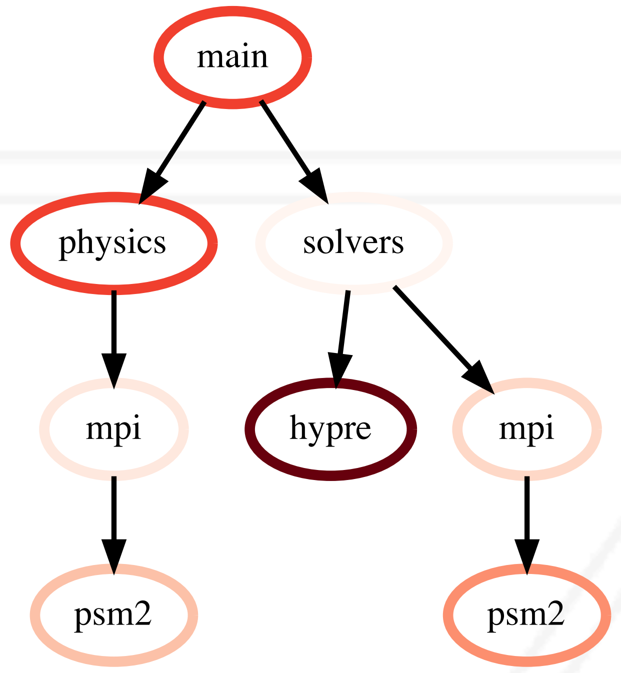

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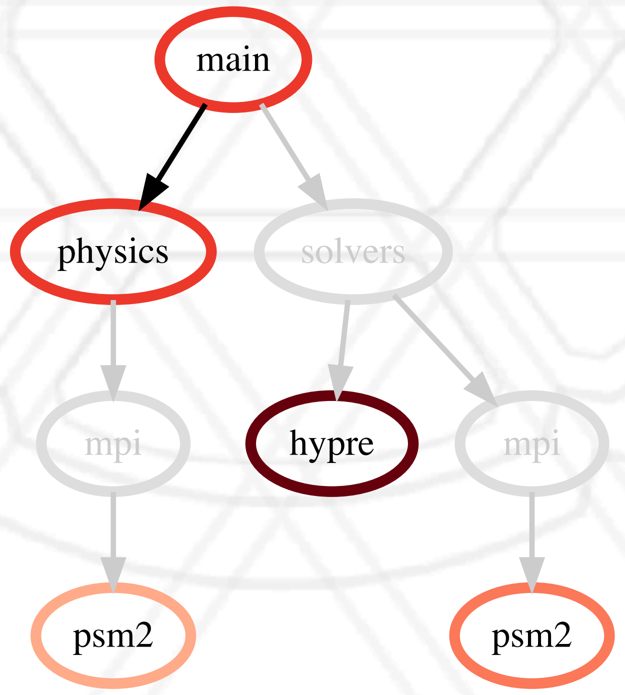

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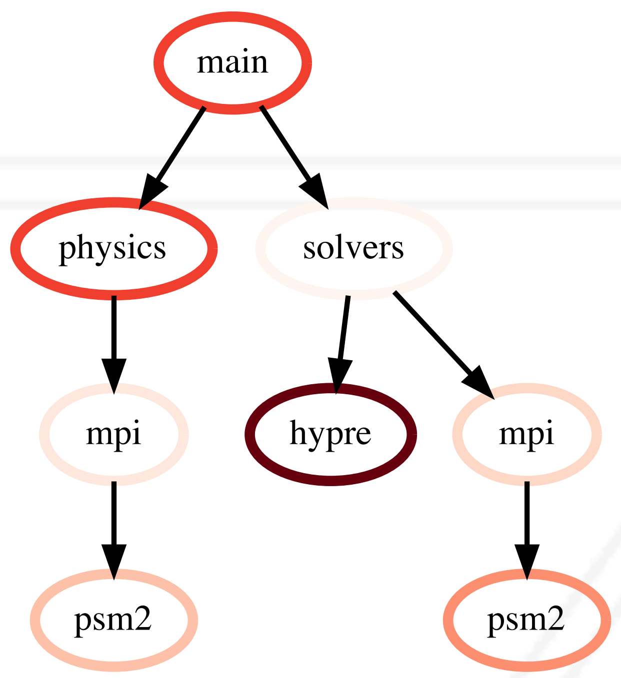

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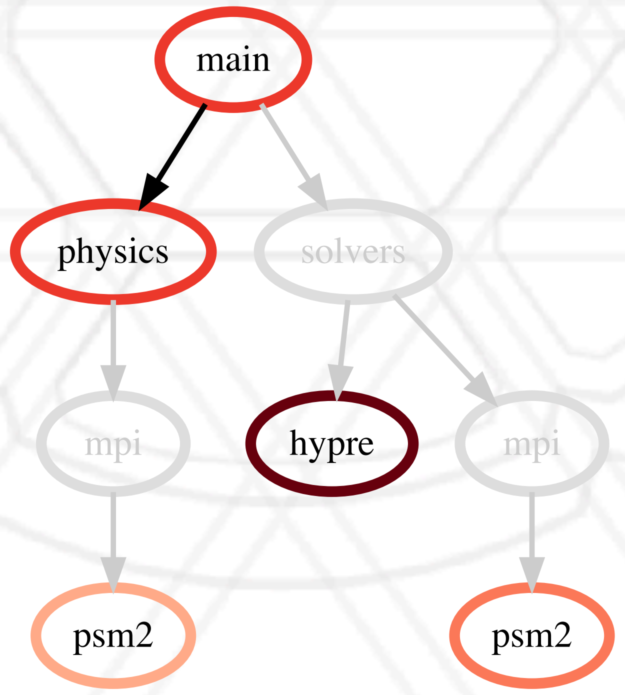

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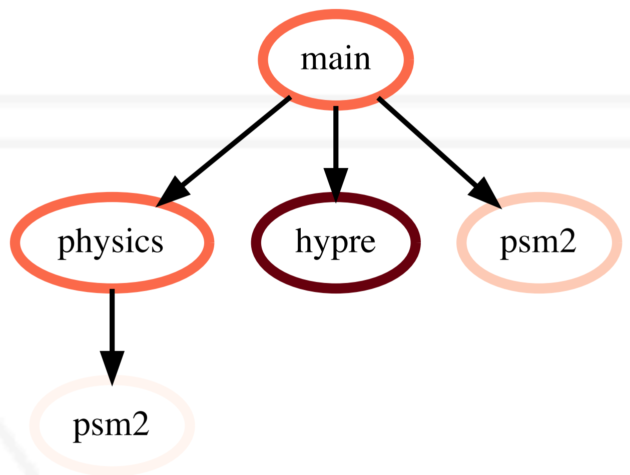

Graphframe operation: subtract

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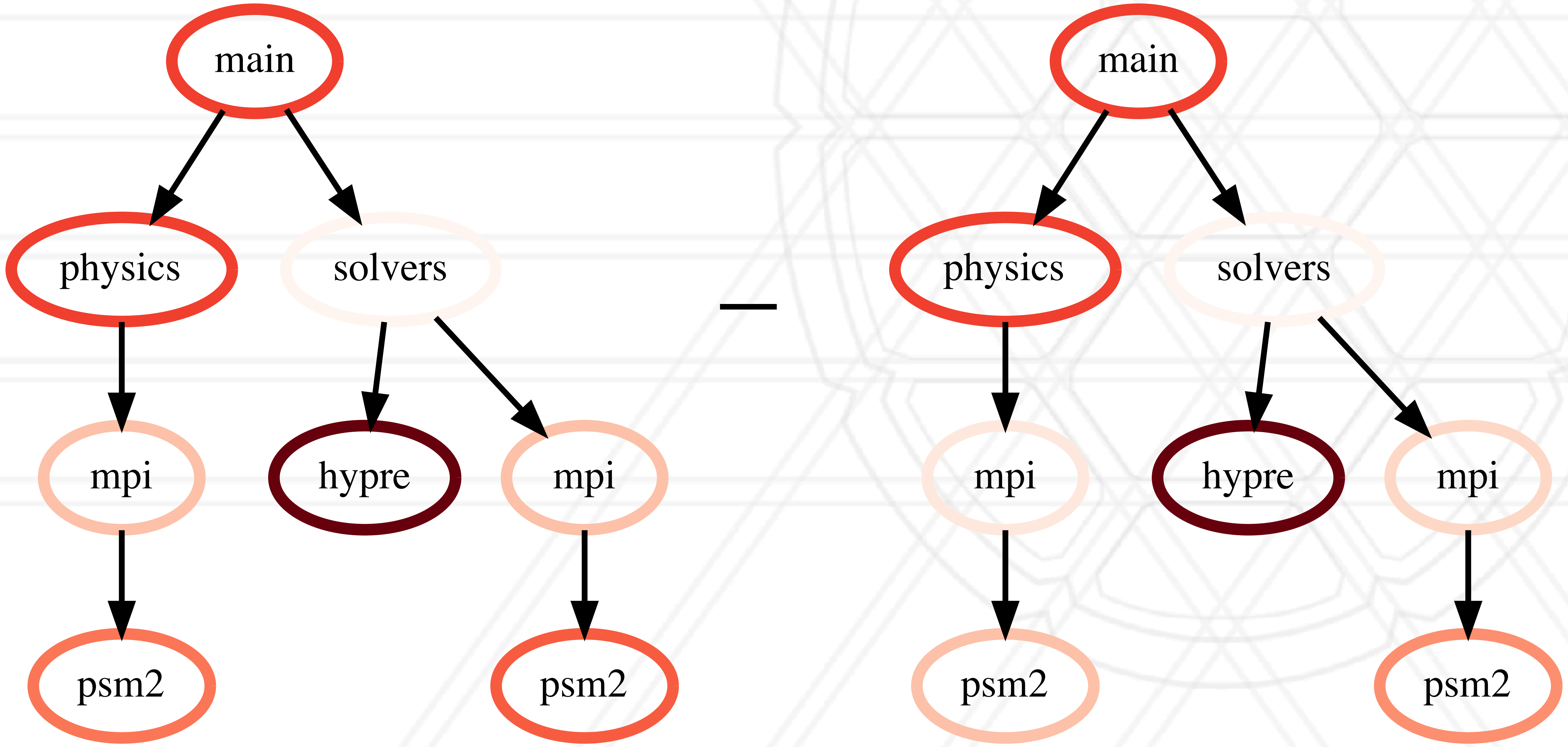

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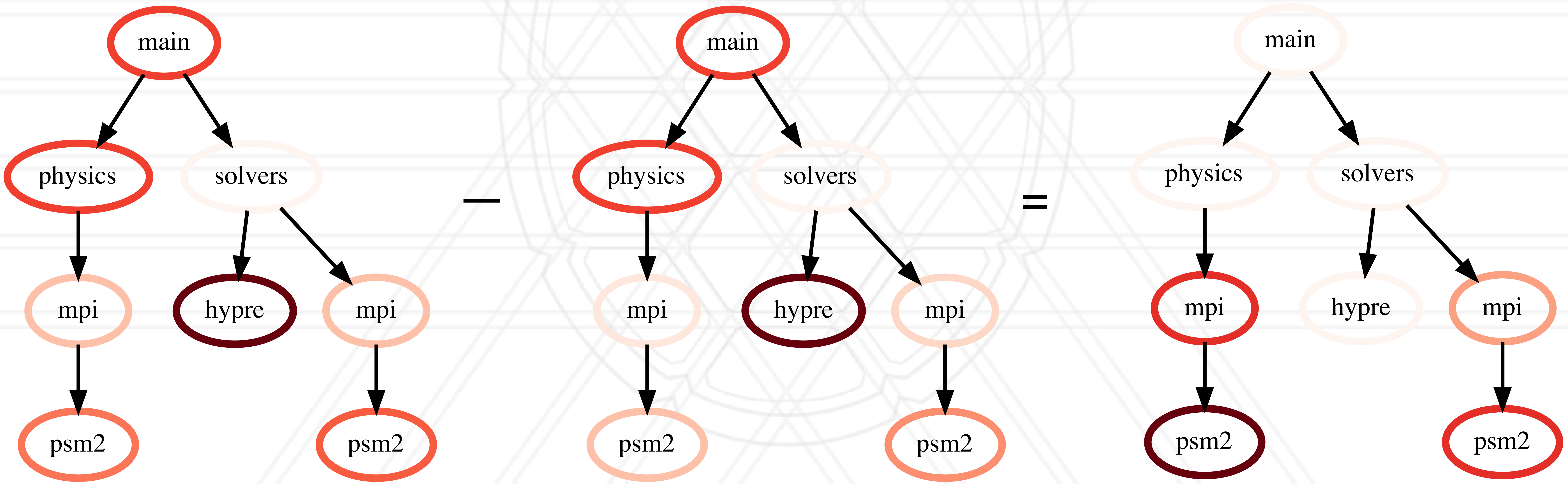

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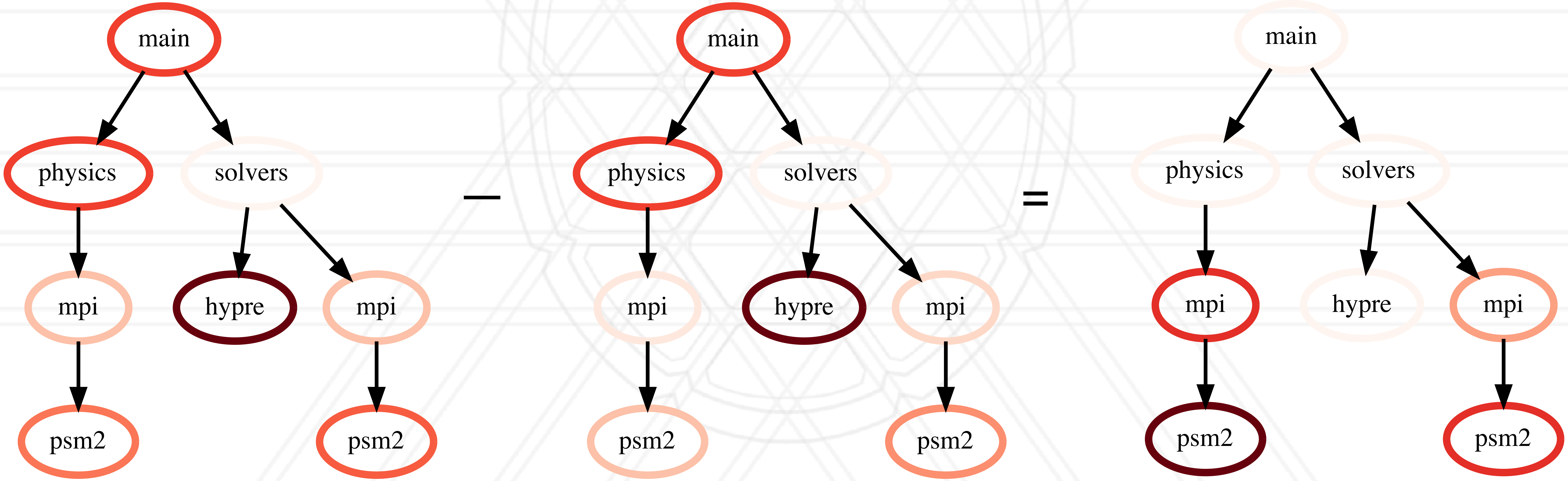

Visualizing *small* graphs

```
print(gf.tree(color=True))
```

```
0.000 foo
├─ 5.000 bar
│  ├─ 5.000 baz
│  └─ 10.000 grault
├─ 0.000 qux
│  └─ 5.000 quux
│     └─ 10.000 corge
│        ├─ 5.000 bar
│        │  ├─ 5.000 baz
│        │  └─ 10.000 grault
│        ├─ 10.000 grault
│        └─ 15.000 garply
└─ 0.000 waldo
   ├─ 5.000 fred
   │  ├─ 5.000 plugh
   │  └─ 5.000 xyzzy
   │     └─ 5.000 thud
   │        ├─ 5.000 baz
   │        └─ 15.000 garply
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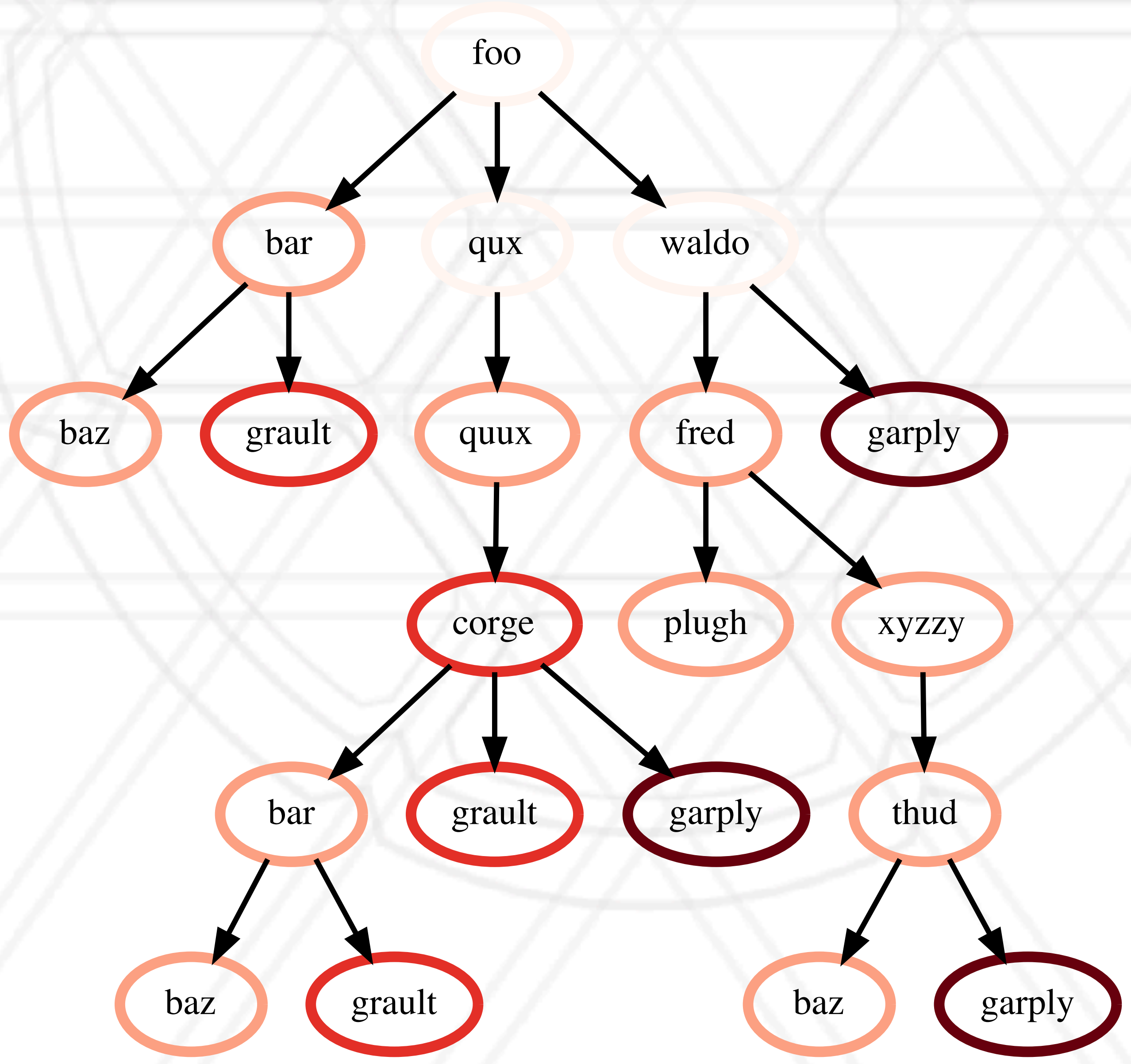
|        |  └─ 10.000 grault
|        ├─ 10.000 grault
|        └─ 15.000 garply
└─ 0.000 waldo
   ├─ 5.000 fred
   |  ├─ 5.000 plugh
   |  └─ 5.000 xyzzy
   |     └─ 5.000 thud
   |        ├─ 5.000 baz
   |        └─ 15.000 garply
   └─ 15.000 garply
```

```
with open("test.dot", "w") as dot_file:
    dot_file.write(gf.to_dot())
```



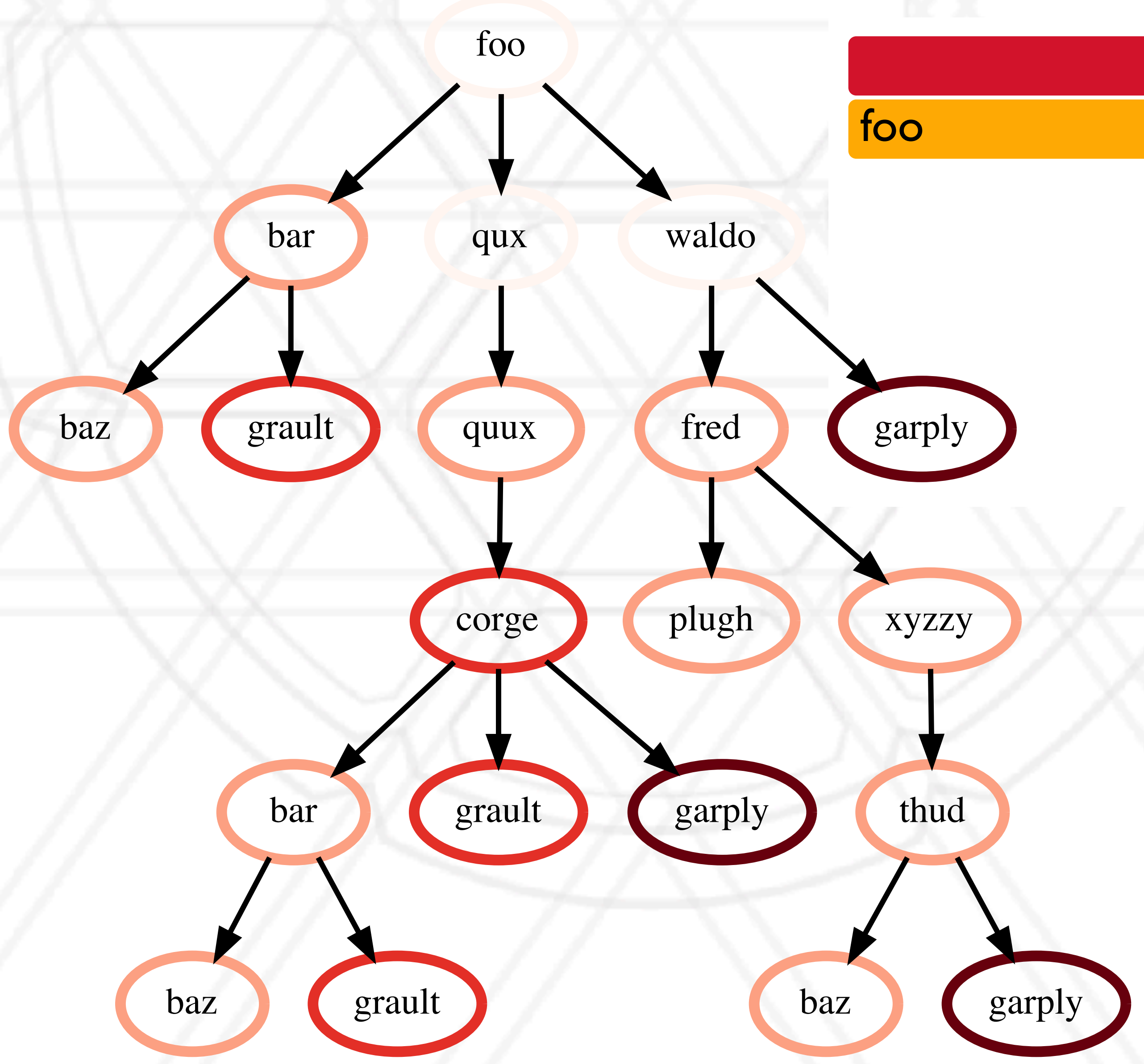
Visualizing *small* graphs

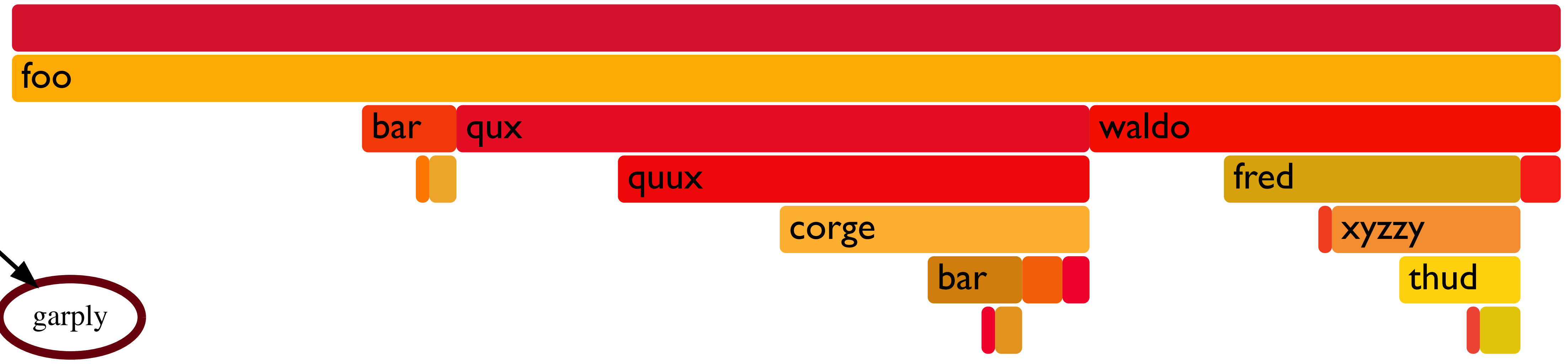
```
print(gf.tree(color=True))
```

```
0.000 foo
├─ 5.000 bar
|  ├─ 5.000 baz
|  └─ 10.000 grault
├─ 0.000 qux
|  └─ 5.000 quux
|     └─ 10.000 corge
|        ├─ 5.000 bar
|        |  ├─ 5.000 baz
|        |  └─ 10.000 grault
|        ├─ 10.000 grault
|        └─ 15.000 garply
└─ 0.000 waldo
   ├─ 5.000 fred
   |  ├─ 5.000 plugh
   |  └─ 5.000 xyzzy
   |     └─ 5.000 thud
   |        ├─ 5.000 baz
   |        └─ 15.000 garply
   └─ 15.000 garply
```

```
with open("test.dot", "w") as dot_file:
    dot_file.write(gf.to_dot())
```

```
with open("test.txt", "w") as folded_stack:
    folded_stack.write(gf.to_flamegraph())
```





Flamegraph

Example 1: Generating a flat profile

```
gf = ht.GraphFrame.from_hpctoolkit('kripke')
gf.drop_index_levels()

grouped = gf.dataframe.groupby('name').sum()
sorted_df = grouped.sort_values(by=['time'], ascending=False)
print(sorted_df)
```

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```

name	nid	time	time (inc)
<unknown file> [kripke]:0	17234	1.825282e+08	1.825282e+08
Kernel_3d_DGZ::scattering	60	7.669936e+07	7.896253e+07
Kernel_3d_DGZ::LTimes	30	5.010439e+07	5.240528e+07
Kernel_3d_DGZ::LPlusTimes	115	4.947707e+07	5.104498e+07
Kernel_3d_DGZ::sweep	981	5.018862e+06	5.018862e+06
memset.S:99	3773	3.168982e+06	3.168982e+06
memset.S:101	3970	2.120895e+06	2.120895e+06
Grid_Data::particleEdit	1201	1.131266e+06	1.249157e+06
<unknown file> [libpsm2.so.2.1]:0	324763	9.733415e+05	9.733415e+05
memset.S:98	3767	6.19777[illegible]e+05	6.197776e+05

Example 2: Comparing two executions

```
gf1 = ht.GraphFrame.from_caliper('lulesh-1core.json')
gf2 = ht.GraphFrame.from_caliper('lulesh-27cores. json')

gf2.drop_index_levels()
gf3 = gf2 - gf1

sorted_df = gf3.dataframe.sort_values(by=['time'], ascending=False)
print(sorted_df)
```

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```

node	name	nid	time	time (inc)
TimeIncrement	TimeIncrement	25.0	8.505048e+06	8.505048e+06
CalcQForElems	CalcQForElems	16.0	4.455672e+06	5.189453e+06
CalcHourglassControlForElems	CalcHourglassControlForElems	7.0	3.888798e+06	4.755817e+06
LagrangeNodal	LagrangeNodal	3.0	1.986046e+06	8.828475e+06
CalcForceForNodes	CalcForceForNodes	4.0	1.017857e+06	6.842429e+06

Example 3: Scaling study

```
datasets = glob.glob('lulesh*.json')
datasets.sort()

dataframes = []
for dataset in datasets:
    gf = ht.GraphFrame.from_caliper(dataset)
    gf.drop_index_levels()

    num_pes = re.match('(.*)-(\d+)(.*)', dataset).group(2)
    gf.dataframe['pes'] = num_pes
    filtered_gf = gf.filter(lambda x: x['time'] > 1e6)
    dataframes.append(filtered_gf.dataframe)

result = pd.concat(dataframes)
pivot_df = result.pivot(index='pes', columns='name', values='time')
pivot_df.loc[:,:].plot.bar(stacked=True, figsize=(10,7))
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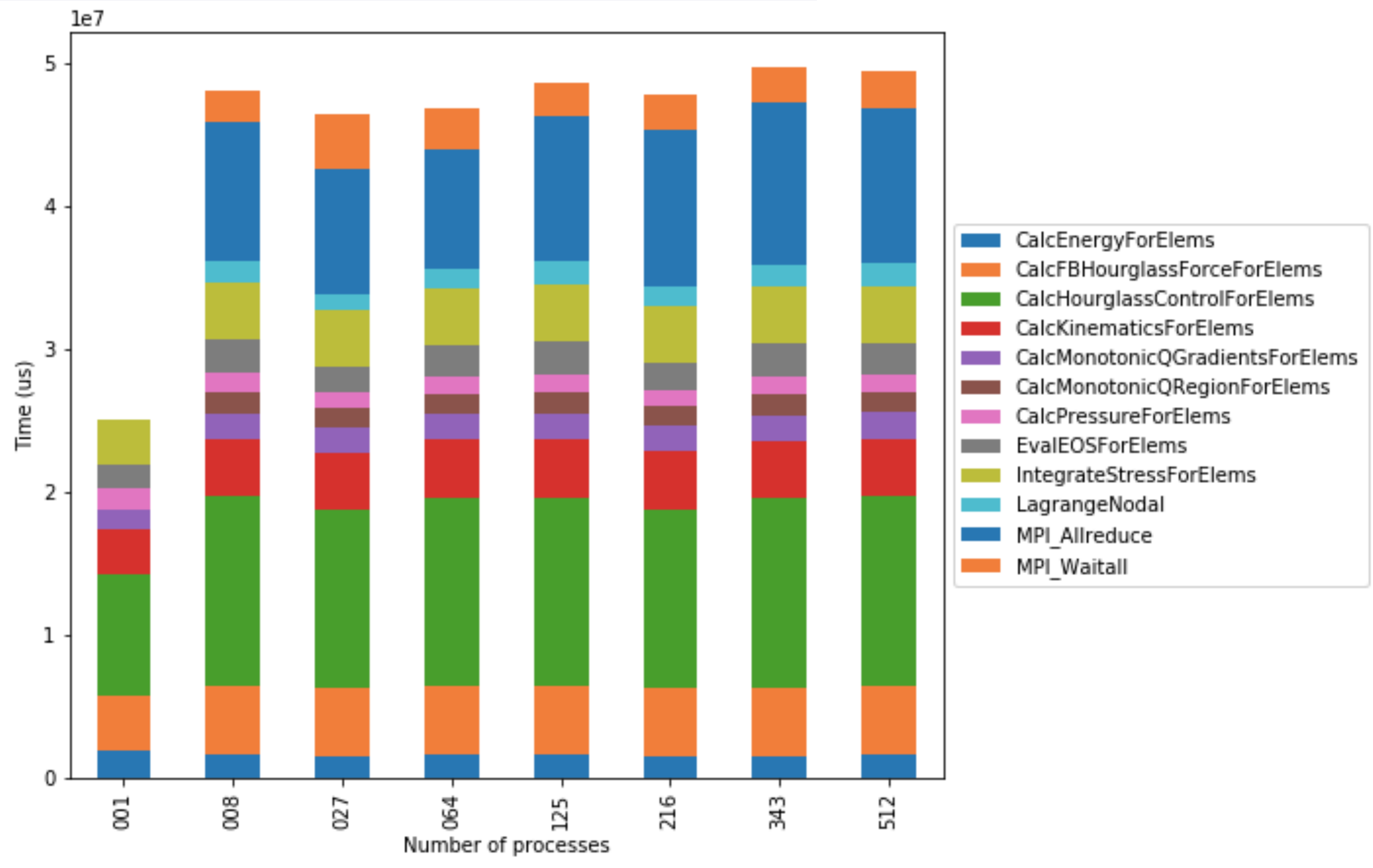

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