Extra-P Meets Hatchet: Towards Modeling in Performance Analytics

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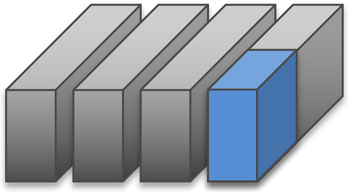
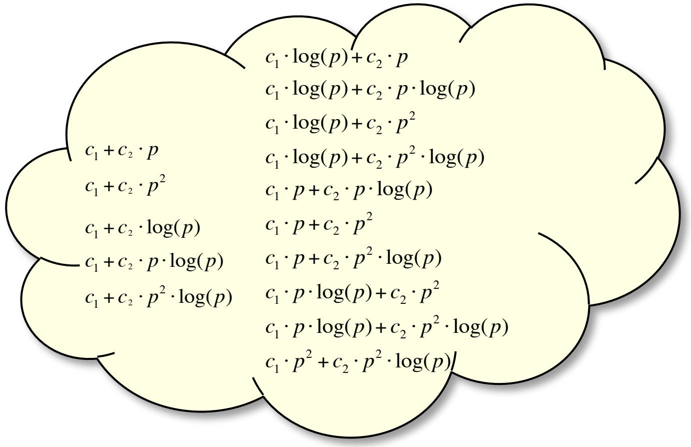
Automatic Performance Modeling



Small-scale measurements

$$f(x_1,\dots,x_m) = \sum_{k=1}^{n} c_k \prod_{l=1}^{m} x_l^{i_{kl}} \cdot \log_2^{j_{kl}}(x_l)$$

Performance model normal form (PMNF)



$c_1 + c_2 \cdot p$

$c_1 + c_2 \cdot p^2$

$c_1 + c_2 \cdot \log(p)$

$c_1 + c_2 \cdot p \cdot \log(p)$

$c_1 + c_2 \cdot p^2 \cdot \log(p)$

$c_1 \cdot \log(p) + c_2 \cdot p$

$c_1 \cdot \log(p) + c_2 \cdot p \cdot \log(p)$

$c_1 \cdot \log(p) + c_2 \cdot p^2$

$c_1 \cdot \log(p) + c_2 \cdot p^2 \cdot \log(p)$

$c_1 \cdot p + c_2 \cdot p \cdot \log(p)$

$c_1 \cdot p + c_2 \cdot p^2$

$c_1 \cdot p + c_2 \cdot p^2 \cdot \log(p)$

$c_1 \cdot p \cdot \log(p) + c_2 \cdot p^2$

$c_1 \cdot p \cdot \log(p) + c_2 \cdot p^2 \cdot \log(p)$

$c_1 \cdot p^2 + c_2 \cdot p^2 \cdot \log(p)$

Generation of candidate models
and selection of best fit

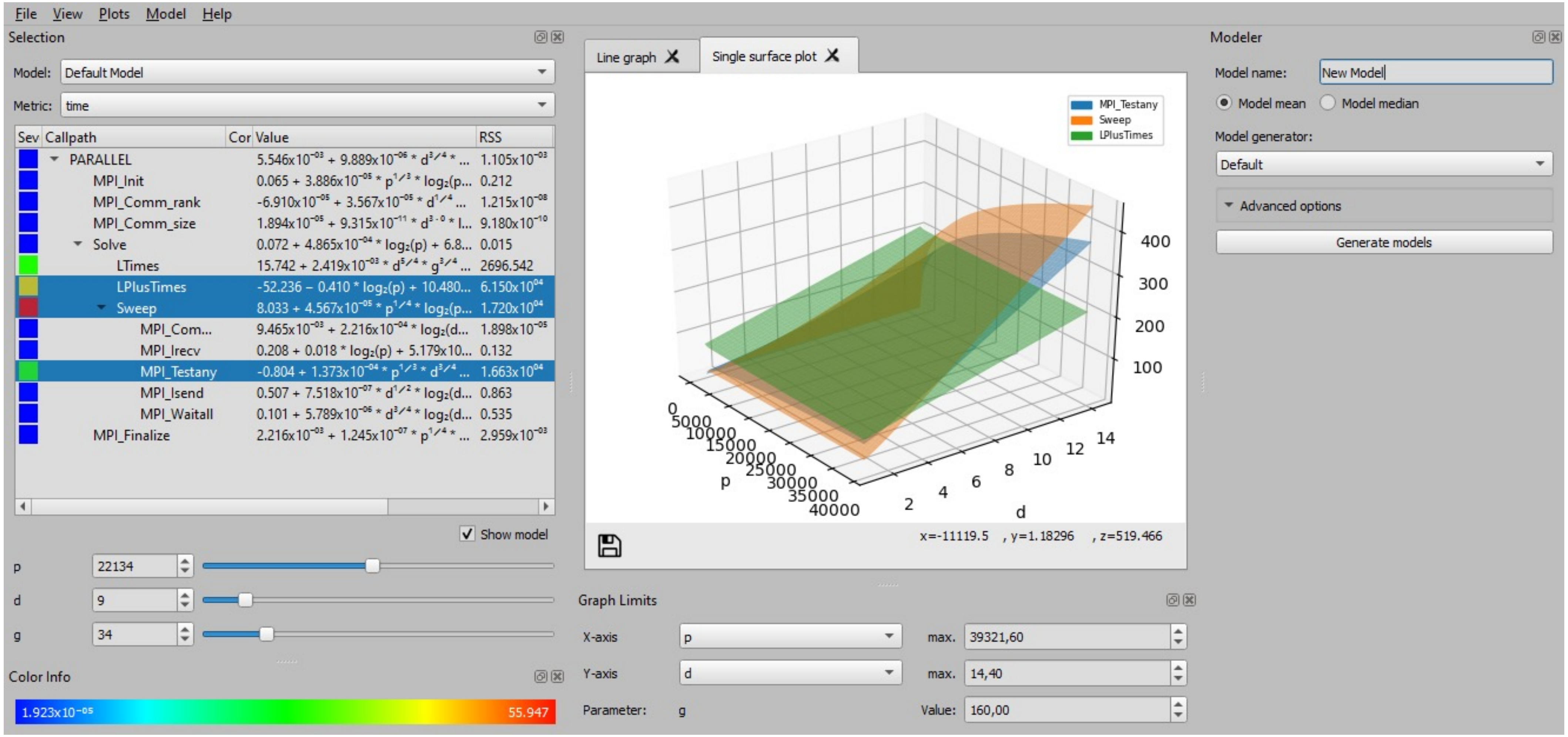
Kernel	Model
sweep → MPI_Recv	$4.03\sqrt{p}$
sweep	582.19
Kripke	$5.4 \cdot d \cdot g$

Calotoiu et al.: Using Automated Performance Modeling to Find Scalability Bugs in Complex Codes (*SC'13*)

Extra-P

- Generates performance models
- Input is performance profiles (e.g., Score-P) or text data
- Both weak and strong scaling models are supported
- Offers both command line and GUI interfaces
- Github repo: https://github.com/Extra-p/extrap

Extra-P GUI



Model: Default Model

Metric: time

Sev	Callpath	Cor	Value	RSS
🟦	PARALLEL		$5.546x10^{-03} + 9.889x10^{-06} * d^{3/4} *$ ...	$1.105x10^{-03}$
🟦	MPI_Init		$0.065 + 3.886x10^{-05} * p^{1/3} * \log_2(p$...	0.212
🟦	MPI_Comm_rank		$-6.910x10^{-05} + 3.567x10^{-05} * d^{1/4}$ ...	$1.215x10^{-08}$
🟦	MPI_Comm_size		$1.894x10^{-05} + 9.315x10^{-11} * d^{3 \cdot 0} *$ l...	$9.180x10^{-10}$
🟦	Solve		$0.072 + 4.865x10^{-04} * \log_2(p) + 6.8$...	0.015
🟩	LTimes		$15.742 + 2.419x10^{-03} * d^{5/4} * g^{3/4}$ ...	2696.542
🟨	LPlusTimes		$-52.236 - 0.410 * \log_2(p) + 10.480$...	$6.150x10^{04}$
🟥	Sweep		$8.033 + 4.567x10^{-05} * p^{1/4} * \log_2(p$...	$1.720x10^{04}$
🟦	MPI_Com...		$9.465x10^{-03} + 2.216x10^{-04} * \log_2(d$...	$1.898x10^{-05}$
🟦	MPI_Irecv		$0.208 + 0.018 * \log_2(p) + 5.179x10$...	0.132
🟩	MPI_Testany		$-0.804 + 1.373x10^{-04} * p^{1/3} * d^{3/4}$ ...	$1.663x10^{04}$
🟦	MPI_Isend		$0.507 + 7.518x10^{-07} * d^{1/2} * \log_2(d$...	0.863
🟦	MPI_Waitall		$0.101 + 5.789x10^{-06} * d^{3/4} * \log_2(d$...	0.535
🟦	MPI_Finalize		$2.216x10^{-03} + 1.245x10^{-07} * p^{1/4} *$ ...	$2.959x10^{-03}$

☑ Show model

p: 22134

d: 9

g: 34

Model name: New Model

● Model mean ○ Model median

Model generator: Default

X-axis: p max. 39321,60

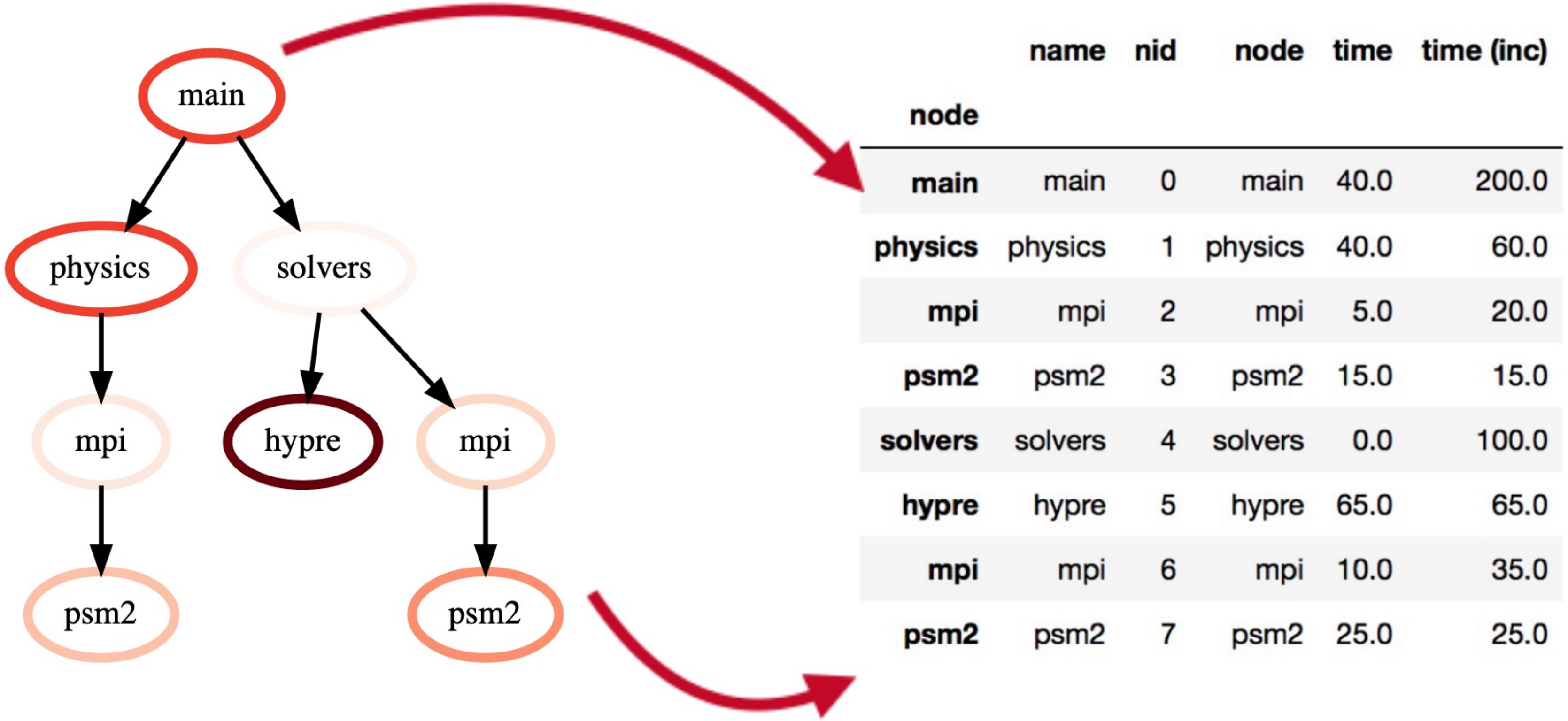
Y-axis: d max. 14,40

Parameter: g Value: 160,00

Hatchet

- A (programmatic) performance analysis tool
- Python-based data science applied to performance analysis
- Supports structured and hierarchical data
- Allows to compare multiple execution profiles, automate analysis in Python scripts
- Github repo: https://github.com/LLNL/Hatchet
- Publications:
  - Bhatele, Brink, Gamblin: “Hatchet: Pruning the Overgrowth in Parallel Profiles” (SC’19)
  - Brink et al.: “Usability and Performance Improvements in Hatchet” (ProTools’20)

Hatchet’s GraphFrame



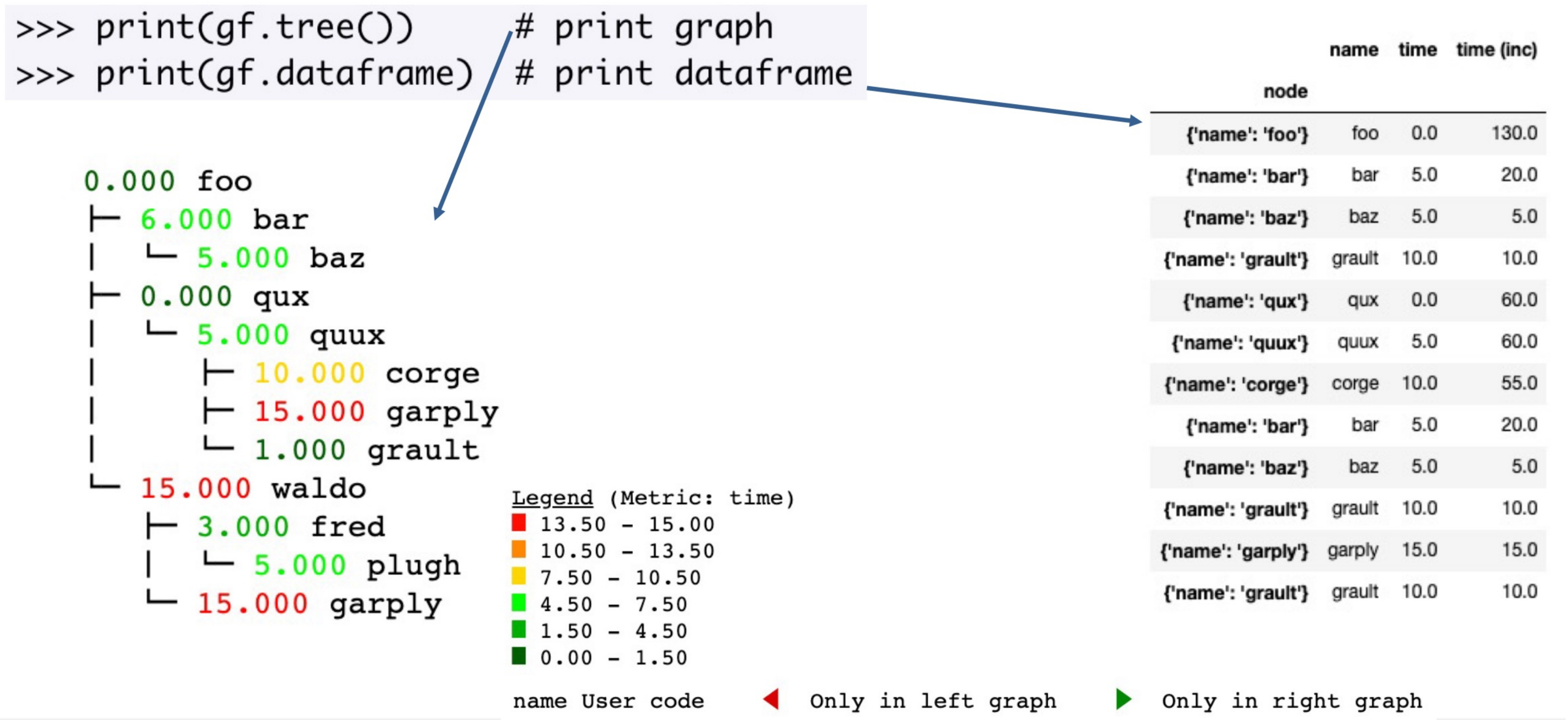
	name	nid	node	time	time (inc)
node					
main	main	0	main	40.0	200.0
physics	physics	1	physics	40.0	60.0
mpi	mpi	2	mpi	5.0	20.0
psm2	psm2	3	psm2	15.0	15.0
solvers	solvers	4	solvers	0.0	100.0
hypre	hypre	5	hypre	65.0	65.0
mpi	mpi	6	mpi	10.0	35.0
psm2	psm2	7	psm2	25.0	25.0

Graph: Stores relationships between parents and children

Pandas Dataframe: 2D table storing numerical data associated with each node (may be unique per rank, per thread)

Hatchet tutorial:
https://hatchet.readthedocs.io/en/latest/publications.html

GraphFrame components



```
>>> print(gf.tree())      # print graph
>>> print(gf.dataframe)   # print dataframe
```

```
0.000 foo
├─ 6.000 bar
│  └─ 5.000 baz
├─ 0.000 qux
│  └─ 5.000 quux
│     ├─ 10.000 corge
│     ├─ 15.000 garply
│     └─ 1.000 grault
└─ 15.000 waldo
   ├─ 3.000 fred
   │  └─ 5.000 plugh
   └─ 15.000 garply
```

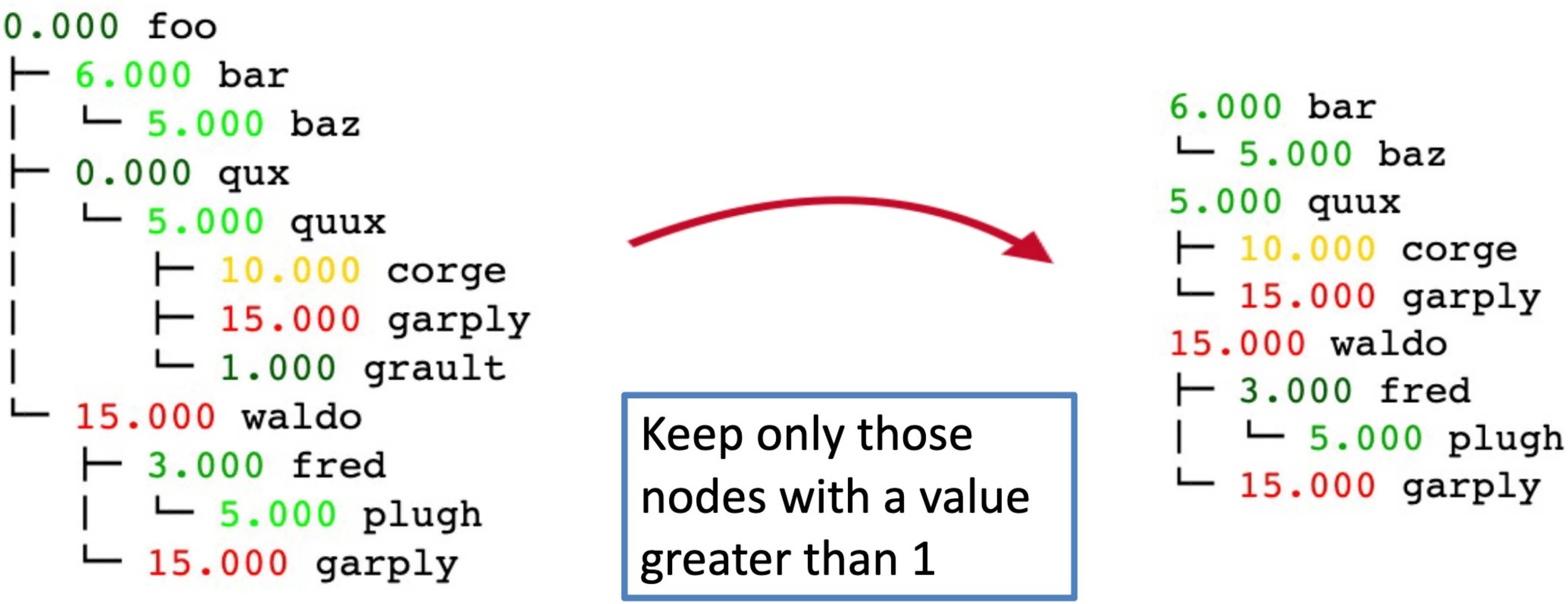
```
Legend (Metric: time)
🟥 13.50 - 15.00
🟧 10.50 - 13.50
🟨 7.50 - 10.50
🟩 4.50 - 7.50
🟩 1.50 - 4.50
🟩 0.00 - 1.50

name User code    ◀ Only in left graph    ▶ Only in right graph
```

node	name	time	time (inc)
{'name': 'foo'}	foo	0.0	130.0
{'name': 'bar'}	bar	5.0	20.0
{'name': 'baz'}	baz	5.0	5.0
{'name': 'grault'}	grault	10.0	10.0
{'name': 'qux'}	qux	0.0	60.0
{'name': 'quux'}	quux	5.0	60.0
{'name': 'corge'}	corge	10.0	55.0
{'name': 'bar'}	bar	5.0	20.0
{'name': 'baz'}	baz	5.0	5.0
{'name': 'grault'}	grault	10.0	10.0
{'name': 'garply'}	garply	15.0	15.0
{'name': 'grault'}	grault	10.0	10.0

Hatchet tutorial:
https://hatchet.readthedocs.io/en/latest/publications.html

Programmatic analysis

```
>>> filter_func = lambda x: x["time"] > 1          # filter function
>>> filt_gf = gf.filter(filter_func, squash=True)  # apply filter and rewire graph
```



```
0.000 foo
├─ 6.000 bar
|   └─ 5.000 baz
├─ 0.000 qux
|   └─ 5.000 quux
|       ├─ 10.000 corge
|       ├─ 15.000 garply
|       └─ 1.000 grault
└─ 15.000 waldo
    ├─ 3.000 fred
    |   └─ 5.000 plugh
    └─ 15.000 garply
```

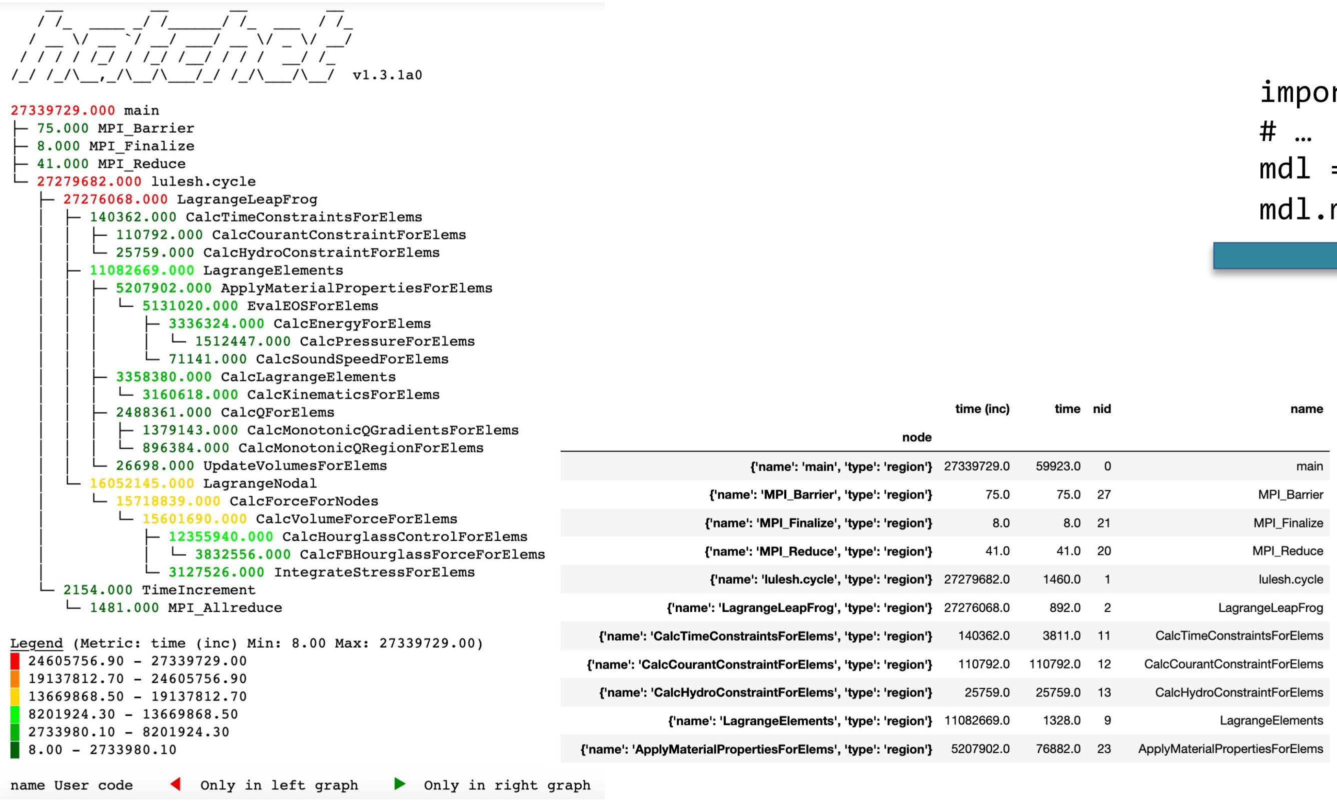
```
6.000 bar
└─ 5.000 baz
5.000 quux
├─ 10.000 corge
└─ 15.000 garply
15.000 waldo
├─ 3.000 fred
|   └─ 5.000 plugh
└─ 15.000 garply
```

Keep only those nodes with a value greater than 1

Hatchet tutorial:
https://hatchet.readthedocs.io/en/latest/publications.html

Integrating Extra-P in Hatchet

- Code in Github: https://github.com/sshudler/hatchet/tree/modeling

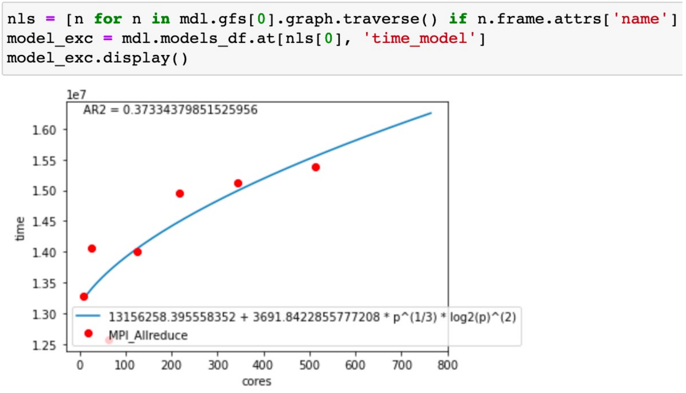


```
    __          __       __         __
   / /_  ____ _/ /______/ /_  ___  / /_
  / __ \/ __ `/ __/ ___/ __ \/ _ \/ __/
 / / / / /_/ / /_/ /__/ / / /  __/ /_
/_/ /_/\__,_/\__/\___/_/ /_/\___/\__/  v1.3.1a0

27339729.000 main
├─ 75.000 MPI_Barrier
├─ 8.000 MPI_Finalize
├─ 41.000 MPI_Reduce
└─ 27279682.000 lulesh.cycle
   ├─ 27276068.000 LagrangeLeapFrog
   │  ├─ 140362.000 CalcTimeConstraintsForElems
   │  │  ├─ 110792.000 CalcCourantConstraintForElems
   │  │  └─ 25759.000 CalcHydroConstraintForElems
   │  ├─ 11082669.000 LagrangeElements
   │  │  ├─ 5207902.000 ApplyMaterialPropertiesForElems
   │  │  │  └─ 5131020.000 EvalEOSForElems
   │  │  │     ├─ 3336324.000 CalcEnergyForElems
   │  │  │     │  └─ 1512447.000 CalcPressureForElems
   │  │  │     └─ 71141.000 CalcSoundSpeedForElems
   │  │  ├─ 3358380.000 CalcLagrangeElements
   │  │  │  └─ 3160618.000 CalcKinematicsForElems
   │  │  ├─ 2488361.000 CalcQForElems
   │  │  │  ├─ 1379143.000 CalcMonotonicQGradientsForElems
   │  │  │  └─ 896384.000 CalcMonotonicQRegionForElems
   │  │  └─ 26698.000 UpdateVolumesForElems
   │  └─ 16052145.000 LagrangeNodal
   │     └─ 15718839.000 CalcForceForNodes
   │        └─ 15601690.000 CalcVolumeForceForElems
   │           ├─ 12355940.000 CalcHourglassControlForElems
   │           │  └─ 3832556.000 CalcFBHourglassForceForElems
   │           └─ 3127526.000 IntegrateStressForElems
   └─ 2154.000 TimeIncrement
      └─ 1481.000 MPI_Allreduce

Legend (Metric: time (inc) Min: 8.00 Max: 27339729.00)
█ 24605756.90 - 27339729.00
█ 19137812.70 - 24605756.90
█ 13669868.50 - 19137812.70
█ 8201924.30 - 13669868.50
█ 2733980.10 - 8201924.30
█ 8.00 - 2733980.10

name User code    ◀ Only in left graph    ▶ Only in right graph
```

	time (inc)	time	nid	name
node				
{'name': 'main', 'type': 'region'}	27339729.0	59923.0	0	main
{'name': 'MPI_Barrier', 'type': 'region'}	75.0	75.0	27	MPI_Barrier
{'name': 'MPI_Finalize', 'type': 'region'}	8.0	8.0	21	MPI_Finalize
{'name': 'MPI_Reduce', 'type': 'region'}	41.0	41.0	20	MPI_Reduce
{'name': 'lulesh.cycle', 'type': 'region'}	27279682.0	1460.0	1	lulesh.cycle
{'name': 'LagrangeLeapFrog', 'type': 'region'}	27276068.0	892.0	2	LagrangeLeapFrog
{'name': 'CalcTimeConstraintsForElems', 'type': 'region'}	140362.0	3811.0	11	CalcTimeConstraintsForElems
{'name': 'CalcCourantConstraintForElems', 'type': 'region'}	110792.0	110792.0	12	CalcCourantConstraintForElems
{'name': 'CalcHydroConstraintForElems', 'type': 'region'}	25759.0	25759.0	13	CalcHydroConstraintForElems
{'name': 'LagrangeElements', 'type': 'region'}	11082669.0	1328.0	9	LagrangeElements
{'name': 'ApplyMaterialPropertiesForElems', 'type': 'region'}	5207902.0	76882.0	23	ApplyMaterialPropertiesForElems

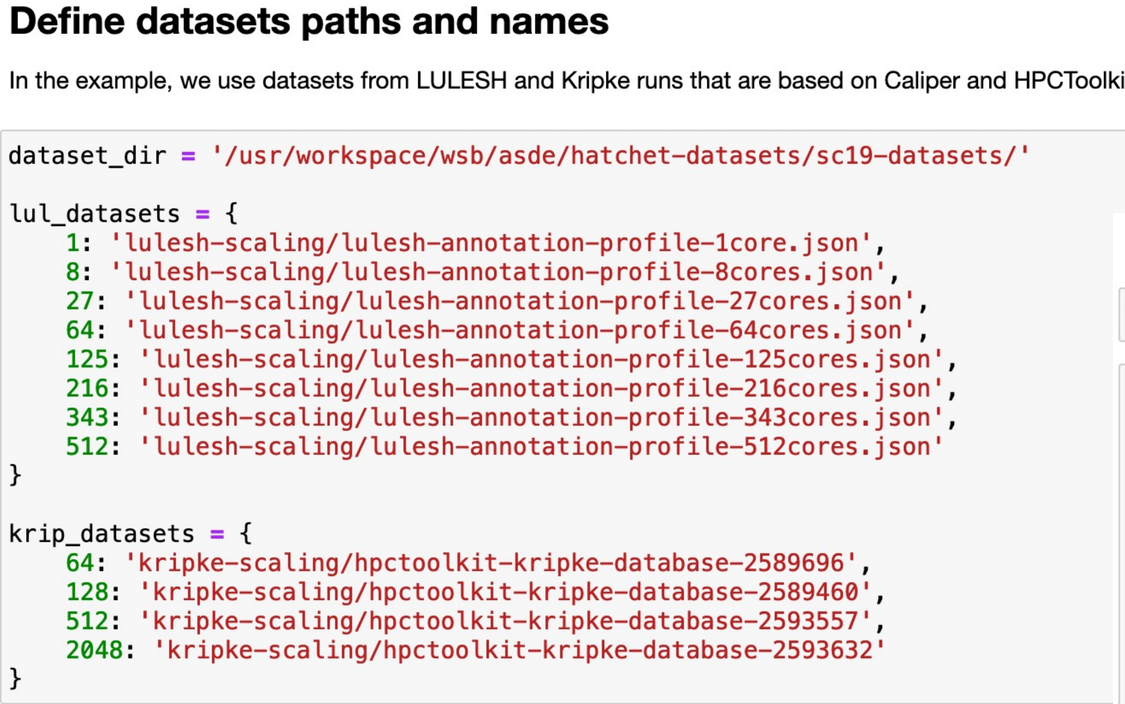
Hatchet GraphFrame (graph + dataframe)

```
import hatchet as ht
# …
mdl = ht.Modeling(…)
mdl.model_all()
```



```
nls = [n for n in mdl.gfs[0].graph.traverse() if n.frame.attrs['name']]
model_exc = mdl.models_df.at[nls[0], 'time_model']
model_exc.display()
```

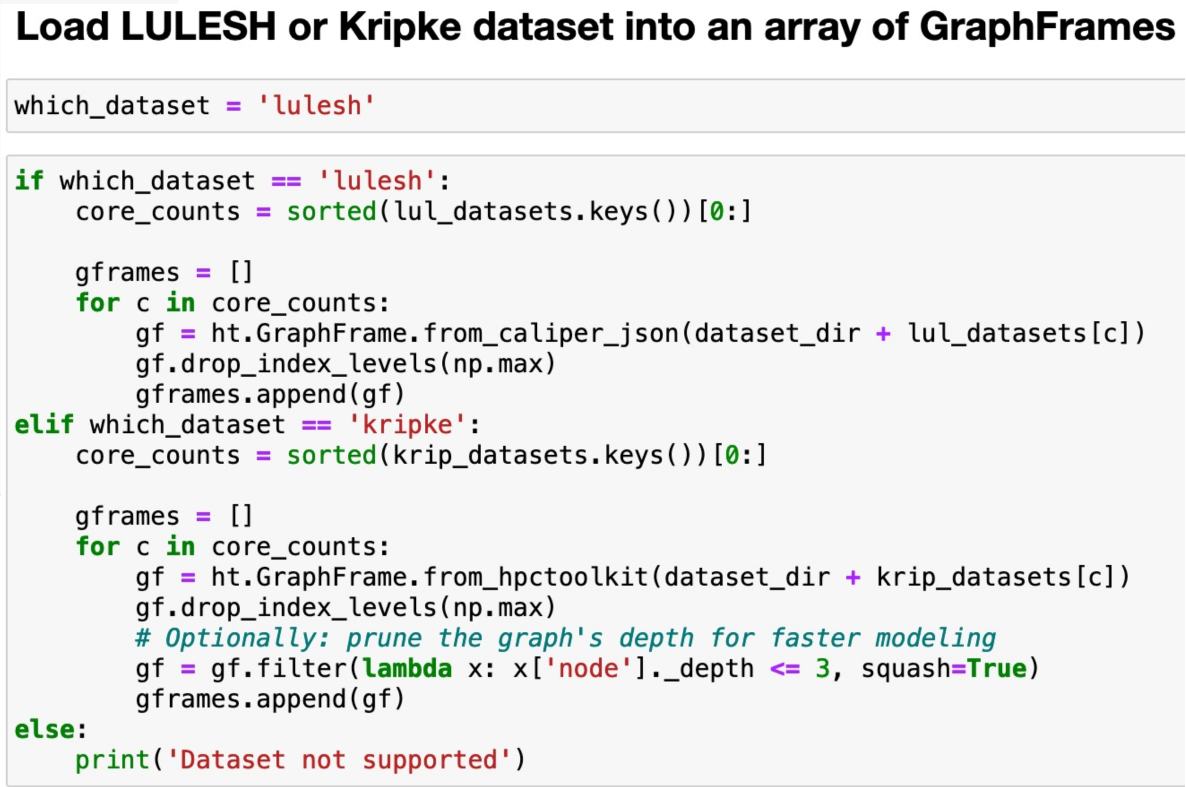
Input: Sequence of GraphFrames



Define datasets paths and names

In the example, we use datasets from LULESH and Kripke runs that are based on Caliper and HPCToolkit, respectively.

```
dataset_dir = '/usr/workspace/wsb/asde/hatchet-datasets/sc19-datasets/'

lul_datasets = {
    1: 'lulesh-scaling/lulesh-annotation-profile-1core.json',
    8: 'lulesh-scaling/lulesh-annotation-profile-8cores.json',
    27: 'lulesh-scaling/lulesh-annotation-profile-27cores.json',
    64: 'lulesh-scaling/lulesh-annotation-profile-64cores.json',
    125: 'lulesh-scaling/lulesh-annotation-profile-125cores.json',
    216: 'lulesh-scaling/lulesh-annotation-profile-216cores.json',
    343: 'lulesh-scaling/lulesh-annotation-profile-343cores.json',
    512: 'lulesh-scaling/lulesh-annotation-profile-512cores.json'
}

krip_datasets = {
    64: 'kripke-scaling/hpctoolkit-kripke-database-2589696',
    128: 'kripke-scaling/hpctoolkit-kripke-database-2589460',
    512: 'kripke-scaling/hpctoolkit-kripke-database-2593557',
    2048: 'kripke-scaling/hpctoolkit-kripke-database-2593632'
}
```

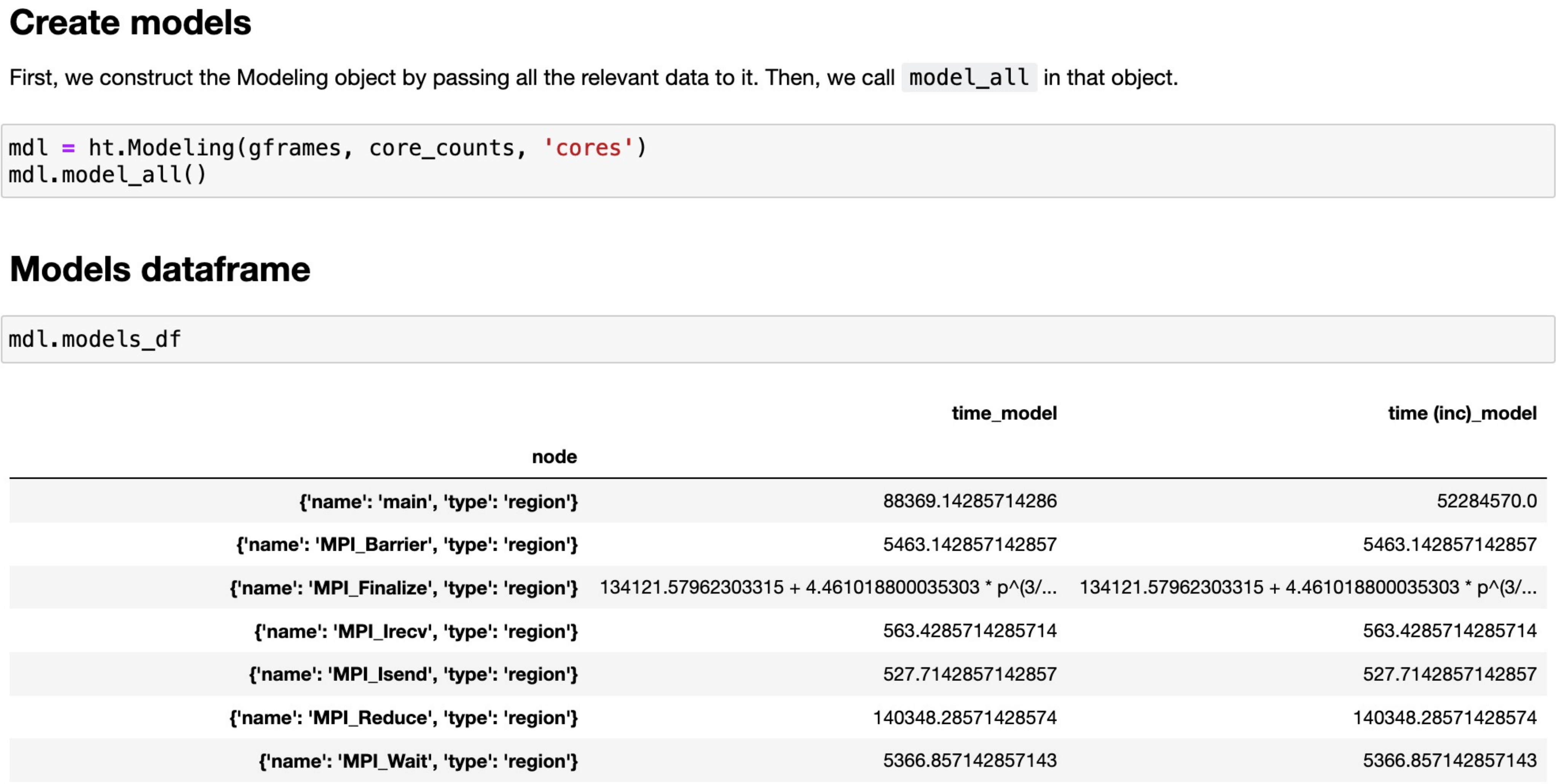


Load LULESH or Kripke dataset into an array of GraphFrames

```
which_dataset = 'lulesh'
```

```
if which_dataset == 'lulesh':
    core_counts = sorted(lul_datasets.keys())[0:]

    gframes = []
    for c in core_counts:
        gf = ht.GraphFrame.from_caliper_json(dataset_dir + lul_datasets[c])
        gf.drop_index_levels(np.max)
        gframes.append(gf)
elif which_dataset == 'kripke':
    core_counts = sorted(krip_datasets.keys())[0:]

    gframes = []
    for c in core_counts:
        gf = ht.GraphFrame.from_hpctoolkit(dataset_dir + krip_datasets[c])
        gf.drop_index_levels(np.max)
        # Optionally: prune the graph's depth for faster modeling
        gf = gf.filter(lambda x: x['node']._depth <= 3, squash=True)
        gframes.append(gf)
else:
    print('Dataset not supported')
```

Producing models



Create models

First, we construct the Modeling object by passing all the relevant data to it. Then, we call `model_all` in that object.

```
mdl = ht.Modeling(gframes, core_counts, 'cores')
mdl.model_all()
```

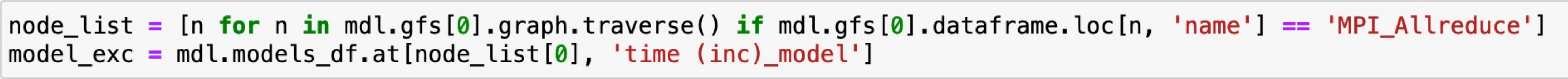
Models dataframe

```
mdl.models_df
```

node	time_model	time (inc)_model
{'name': 'main', 'type': 'region'}	88369.14285714286	52284570.0
{'name': 'MPI_Barrier', 'type': 'region'}	5463.142857142857	5463.142857142857
{'name': 'MPI_Finalize', 'type': 'region'}	134121.57962303315 + 4.461018800035303 * p^(3/...	134121.57962303315 + 4.461018800035303 * p^(3/...
{'name': 'MPI_Irecv', 'type': 'region'}	563.4285714285714	563.4285714285714
{'name': 'MPI_Isend', 'type': 'region'}	527.7142857142857	527.7142857142857
{'name': 'MPI_Reduce', 'type': 'region'}	140348.28571428574	140348.28571428574
{'name': 'MPI_Wait', 'type': 'region'}	5366.857142857143	5366.857142857143

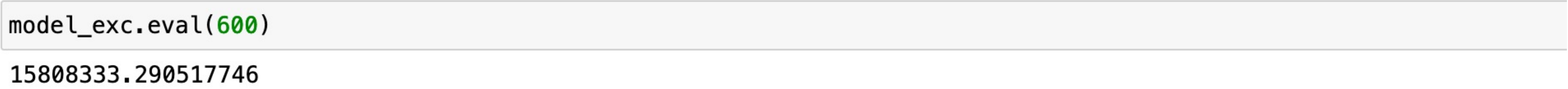
Operations on specific model

- Query the model:



```
node_list = [n for n in mdl.gfs[0].graph.traverse() if mdl.gfs[0].dataframe.loc[n, 'name'] == 'MPI_Allreduce']
model_exc = mdl.models_df.at[node_list[0], 'time (inc)_model']
```

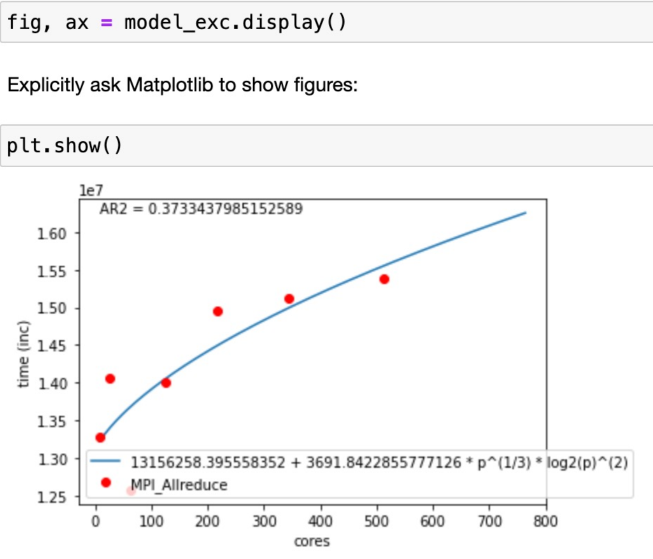
- Evaluate values:



```
model_exc.eval(600)
```

```
15808333.290517746
```

- Display the model:

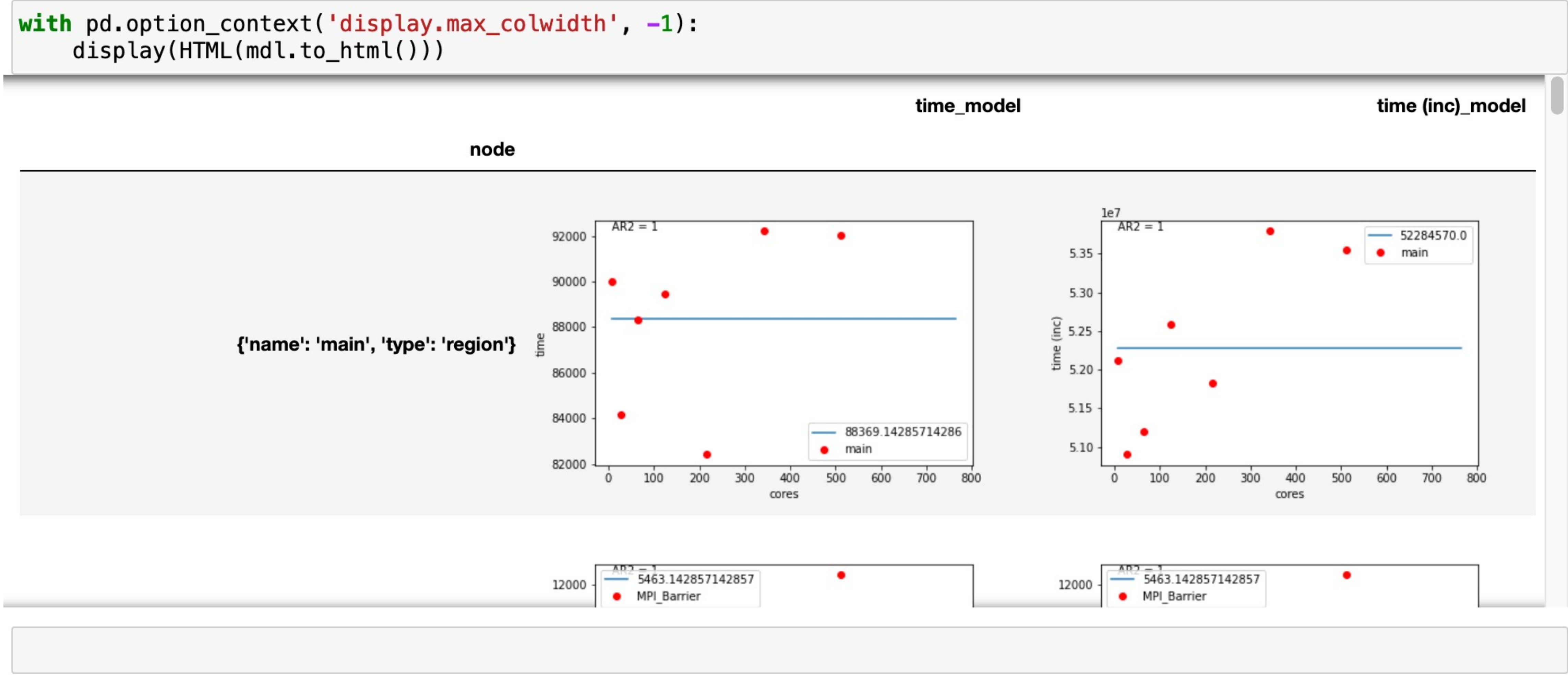


```
fig, ax = model_exc.display()
```

Explicitly ask Matplotlib to show figures:

```
plt.show()
```

Models dataframe with embedded plots



```
with pd.option_context('display.max_colwidth', -1):
    display(HTML(mdl.to_html()))
```

node	time_model	time (inc)_model
{'name': 'main', 'type': 'region'}		

Live demo with Binder

- https://mybinder.org/v2/gh/sshudler/hatchet.git/modeling
- docs/examples/tutorial/hatchet_modeling_demo.ipynb

Conclusion

- Enhance performance analytics with modeling capabilities
- Expand the Extra-P – Hatchet integration to 2+ parameters models
- Experiment with datasets on a longer timeline (SPOT)
- Gather some user feedback

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