

RADICAL-Learning

Radical.hpo

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What is HPO?

- Any machine learning model has some values (hyperparameters) that need to be specified a priori before the training of the dataset.
 - They help adapt the model to the data and they influence the quality of the prediction.
- Hyperparameter optimization deals with the search of the best combination of values for the given model, and there are already many methods that help us find them

Background

- There already exists HyperSpace, a parallel Bayesian Model-Based Optimization (parallel Bayesian SMBO) library with one of the main goals of optimizing model performance with respect to hyperparameters. It supports Scikit-Optimize, RoBo and Hyperband
 - i.e, we can run a bag-of-tasks of optimizations where each task runs the Gaussian process that explores a search space (hyperspace)

Goal

- Since our HPO module wants to integrate HyperSpace with EnTK, the logical path to follow is to treat each hyperspace optimization as an independent task, and set up a bag (stage) of tasks inside a single pipeline
 - We take full advantage of EnTK and achieve concurrency at EnTK level, while still making use of HyperSpace's spaces creation and optimization through its supported HPO engines

Requirements

- Functional

- It must satisfy Bayesian Model-Based Optimization (SMBO) requirements:
 - Define a machine learning model (or objective function)
 - Provide with train/test datasets (if ML model selected)
 - Define a validation protocol: cross-validation (if ML model selected)
 - Define the parameter search space: upper and lower bounds for each hyperparameter
 - Define the optimization function: Gaussian process with guided sampling
- Must use RADICAL-EnTK

- Non-Functional

- The code must be simple
- The code must be easy to maintain

- Non-Functional

- It must use the maximum number of cores available on the largest XSEDE machine, without significant overhead

Execution of HyperSpace

- HyperSpaces use Scikit-Optimize
- Creates combinations of hyperparameters (hyperspaces) using overlapping boundaries between hyperparameters
- Bag-of-tasks are executed with mpi4py
- Number of tasks depends on the number of hyperparameters for the model:
 - $\text{HyperSpaces} = 2^H$ where H is the number of hyperparameters
 - Avg. num of hyperparameters $\sim 7-8$ but depending on model can go up to 12
 - Each optimization runs for N -iterations, where N is ~ 100
- Tasks (Bayesian optimization step) are independent on HyperSpace, requiring each 1 MPI Rank at minimum and using 1 core each

Minimal Example: Styblinski-Tang

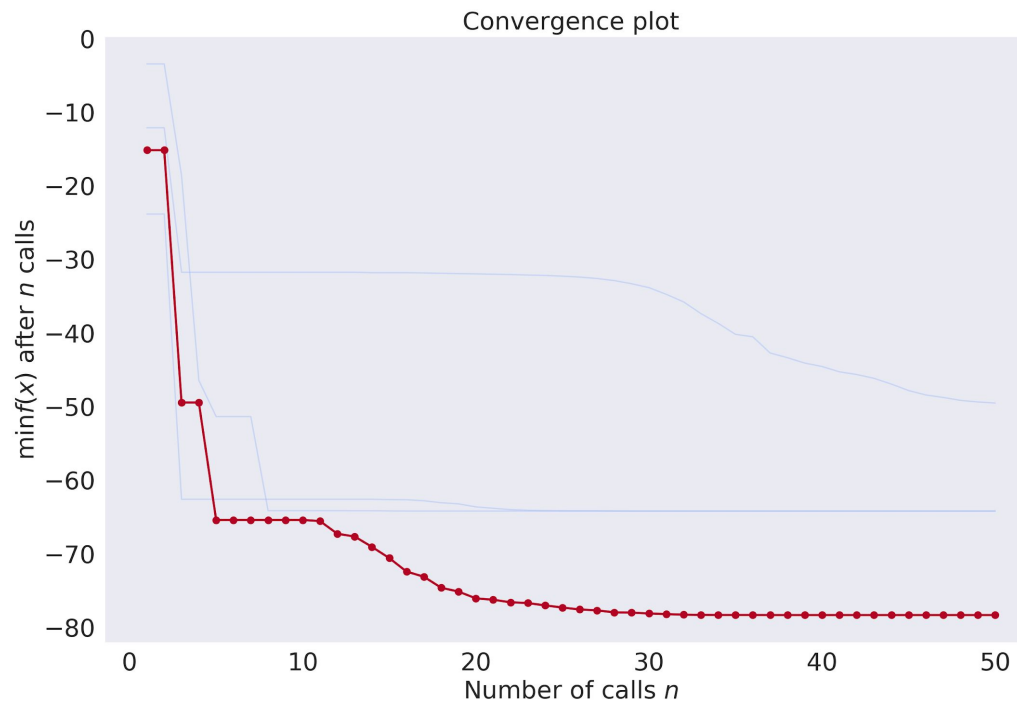
```
Time taken: 0.8317
Function value obtained: -46.8635
Current minimum: -46.8635
Iteration No: 48 started. Searching for the next optimal point.
Iteration No: 48 ended. Search finished for the next optimal point.
Time taken: 0.9449
Function value obtained: -47.2895
Current minimum: -47.2895
Iteration No: 49 started. Searching for the next optimal point.
Iteration No: 49 ended. Search finished for the next optimal point.
Time taken: 0.9206
Function value obtained: -47.7904
Current minimum: -47.7904
Iteration No: 50 started. Searching for the next optimal point.
Iteration No: 50 ended. Search finished for the next optimal point.
Time taken: 1.1440
Function value obtained: -48.0842
Current minimum: -48.0842
/home/karahbit/miniconda3/envs/radical.hpo/lib/python3.6/site-packages/scikit_learn-0.21.3-py3.6-linux-x86_64.egg/sklearn/externals/joblib/__init__.py:15: DeprecationWarning:
sklearn.externals.joblib is deprecated in 0.21 and will be removed in 0.23. Please imp
ort this functionality directly from joblib, which can be installed with: pip install j
oblib. If this warning is raised when loading pickled models, you may need to re-serial
ize those models with scikit-learn 0.21+.
warnings.warn(msg, category=DeprecationWarning)
Command being timed: "mpirun -n 4 python3 benchmark.py --ndims 2 --results /hom
e/karahbit"
User time (seconds): 0.02
System time (seconds): 0.02
Percent of CPU this job got: 0%
Elapsed (wall clock) time (h:mm:ss or m:ss): 0:30:16
Average shared text size (kbytes): 0
Average unshared data size (kbytes): 0
Average stack size (kbytes): 0
Average total size (kbytes): 0
Maximum resident set size (kbytes): 5240
Average resident set size (kbytes): 0
Major (requiring I/O) page faults: 0
Minor (reclaiming a frame) page faults: 4484
Voluntary context switches: 127
Involuntary context switches: 64
Swaps: 0
File system inputs: 0
File system outputs: 0
Socket messages sent: 0
Socket messages received: 0
Signals delivered: 0
Page size (bytes): 4096
Exit status: 0
(radical.hpo) [karahbit@s088 hyperdrive]$ /usr/bin/time -v mpirun -n 4 python3 benchmar
k.py --ndims 2 --results /home/karahbit
[0] <bit>@r018:~/hyperspace/benchmarks/styblinski_tang/hyperdrive$ "two" 07:28 14-Nov-19
```

```
1 [ 0.0%] 8 [|||||100.0%] 15 [|||||100.0%] 22 [|||||100.0%]
2 [ 0.7%] 9 [ 0.0%] 16 [ 0.0%] 23 [ 0.0%]
3 [ 0.0%] 10 [ 0.7%] 17 [ 0.0%] 24 [ 0.0%]
4 [ 0.0%] 11 [ 0.0%] 18 [ 0.0%] 25 [ 0.0%]
5 [ 0.0%] 12 [ 0.0%] 19 [ 0.0%] 26 [ 0.0%]
6 [ 0.0%] 13 [ 0.0%] 20 [ 0.0%] 27 [ 0.0%]
7 [|||||100.0%] 14 [ 0.0%] 21 [ 0.0%] 28 [ 0.0%]
Mem| 3.65G/124G Tasks: 69, 97 thr: 5 running
Swp| 60.5M/16.8G Load average: 2.55 3.80 11.29
Uptime: 21 days, 13:42:11
```

PID	USER	PRI	NI	VIRT	RES	SHR	S	CPU%	MEM%	TIME+	Command
21310	karahbit	20	0	33.0G	212M	104M	R	100.0	0.2	0:17.52	python3 benchmark.py --n
21309	karahbit	20	0	33.0G	207M	104M	R	99.6	0.2	0:17.55	python3 benchmark.py --n
21308	karahbit	20	0	33.0G	216M	104M	R	99.6	0.2	0:17.55	python3 benchmark.py --n
21311	karahbit	20	0	33.0G	208M	104M	R	99.6	0.2	0:17.50	python3 benchmark.py --n
20713	karahbit	20	0	120M	2508	1464	R	0.7	0.0	0:01.80	htop
24776	root	20	0	624M	503M	2328	S	0.0	0.4	1h35:29	/var/lib/pcp/pmdas/proc/
7747	pcp	20	0	106M	4884	3032	S	0.0	0.0	8:44.51	/var/lib/pcp/pmdas/perfe
7750	pcp	20	0	106M	4884	3032	S	0.0	0.0	5:30.30	/var/lib/pcp/pmdas/perfe
20180	root	20	0	334M	3524	2568	S	0.0	0.0	0:00.07	slurmstepd: [6821394.0]
2741	root	20	0	379M	74868	8644	S	0.0	0.1	2:23.25	/opt/puppetlabs/puppet/b
21296	root	20	0	204M	3436	2516	S	0.0	0.0	0:00.02	slurmstepd: [6821394.4]
2078	root	20	0	3388M	56820	10000	S	0.0	0.0	0:05.25	/opt/packages/slurm/defa
21049	nscd	20	0	1502M	2408	1404	S	0.0	0.0	0:41.38	/usr/sbin/nscd
21287	karahbit	20	0	15004	1704	1360	S	0.0	0.0	0:00.01	mpiexec.hydra -n 4 pytho
21303	karahbit	20	0	16716	1640	1280	S	0.0	0.0	0:00.01	/opt/intel/compilers_and
5820	root	20	0	561M	19652	6316	S	0.0	0.0	2:50.89	/usr/bin/python2 -Es /us
1	root	20	0	187M	4792	2616	S	0.0	0.0	8:13.33	/usr/lib/systemd/systemd
5996	root	20	0	561M	19652	6316	S	0.0	0.0	2:50.65	/usr/bin/python2 -Es /us
5341	polkitd	20	0	599M	14404	4784	S	0.0	0.0	0:13.52	/usr/lib/polkit-1/polkit
18764	root	20	0	21768	1428	996	S	0.0	0.0	6:15.24	/usr/sbin/irqbalance --f
6276	root	20	0	413M	3704	776	S	0.0	0.0	5:07.22	hpsamlited -f /dev/hpilo
5874	root	20	0	405M	124M	14652	S	0.0	0.1	1:25.33	/usr/sbin/rsyslogd -n
6754	root	20	0	10640	616	488	S	0.0	0.0	0:44.58	/opt/hp/hp-health/bin/hp
5760	munge	20	0	735M	2392	1932	S	0.0	0.0	0:12.63	/usr/sbin/munged --num-t
20177	root	20	0	267M	3204	2424	S	0.0	0.0	0:00.03	slurmstepd: [6821394.ext
6278	root	20	0	413M	3704	776	S	0.0	0.0	1:24.72	hpsamlited -f /dev/hpilo
6260	root	20	0	93536	3008	2292	S	0.0	0.0	1:44.55	/var/lib/pcp/pmdas/linux
6137	root	20	0	718M	5284	3372	S	0.0	0.0	0:46.43	/usr/sbin/automount --fo
5863	root	20	0	405M	124M	14652	S	0.0	0.1	1:37.08	/usr/sbin/rsyslogd -n
20197	karahbit	20	0	114M	2320	1672	S	0.0	0.0	0:00.06	/bin/bash
20196	root	20	0	334M	3524	2568	S	0.0	0.0	0:00.02	slurmstepd: [6821394.0]
11915	root	20	0	296M	69652	9984	S	0.0	0.1	0:23.78	/opt/puppetlabs/puppet/b
21050	nscd	20	0	1502M	2408	1404	S	0.0	0.0	0:05.70	/usr/sbin/nscd
6149	pcp	20	0	172M	3364	2224	S	0.0	0.0	0:54.45	/usr/libexec/pcp/bin/pmc
21223	postfix	20	0	91296	3908	2928	S	0.0	0.0	0:02.04	qmgr -l -t unix -u
7751	root	20	0	203M	5700	3452	S	0.0	0.0	1:04.73	perl /var/lib/pcp/pmdas/
2743	root	20	0	379M	74868	8644	S	0.0	0.1	0:00.00	/opt/puppetlabs/puppet/b
2744	root	20	0	379M	74868	8644	S	0.0	0.1	0:00.69	/opt/puppetlabs/puppet/b
2762	root	20	0	379M	74868	8644	S	0.0	0.1	0:20.78	/opt/puppetlabs/puppet/b

```
[0] <bit>@r018:~/hyperspace/benchmarks/styblinski_tang/hyperdrive$ "two" 07:28 14-Nov-19
F1Help F2Setup F3SearchF4FilterF5Tree F6SortByF7Nice F8Nice F9Kill F10Quit
```

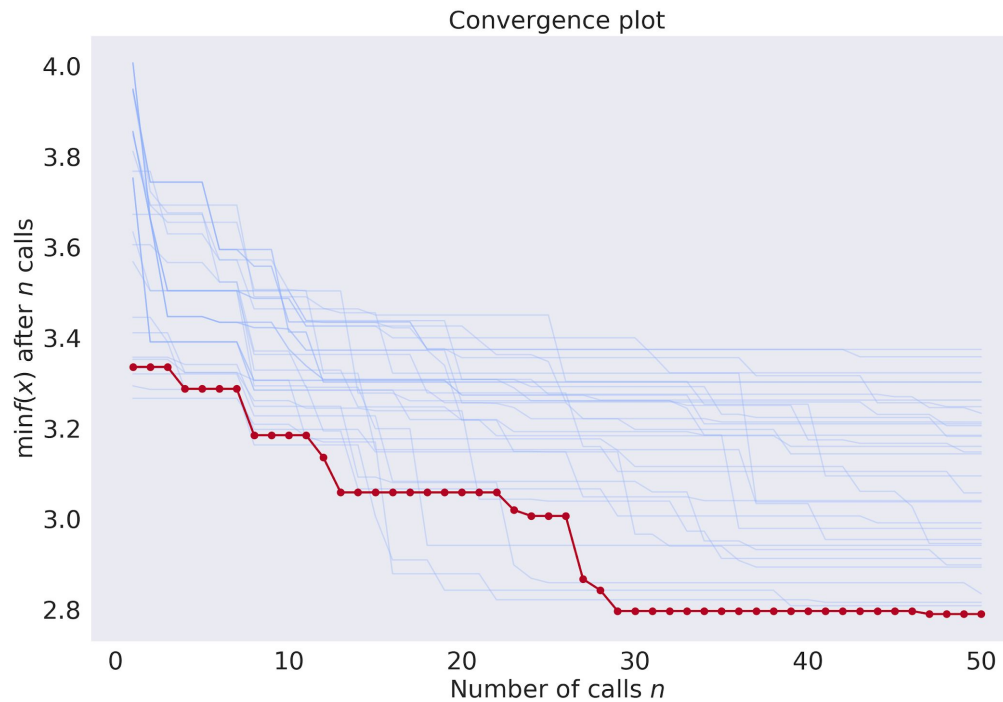
Minimal Example: Styblinski-Tang



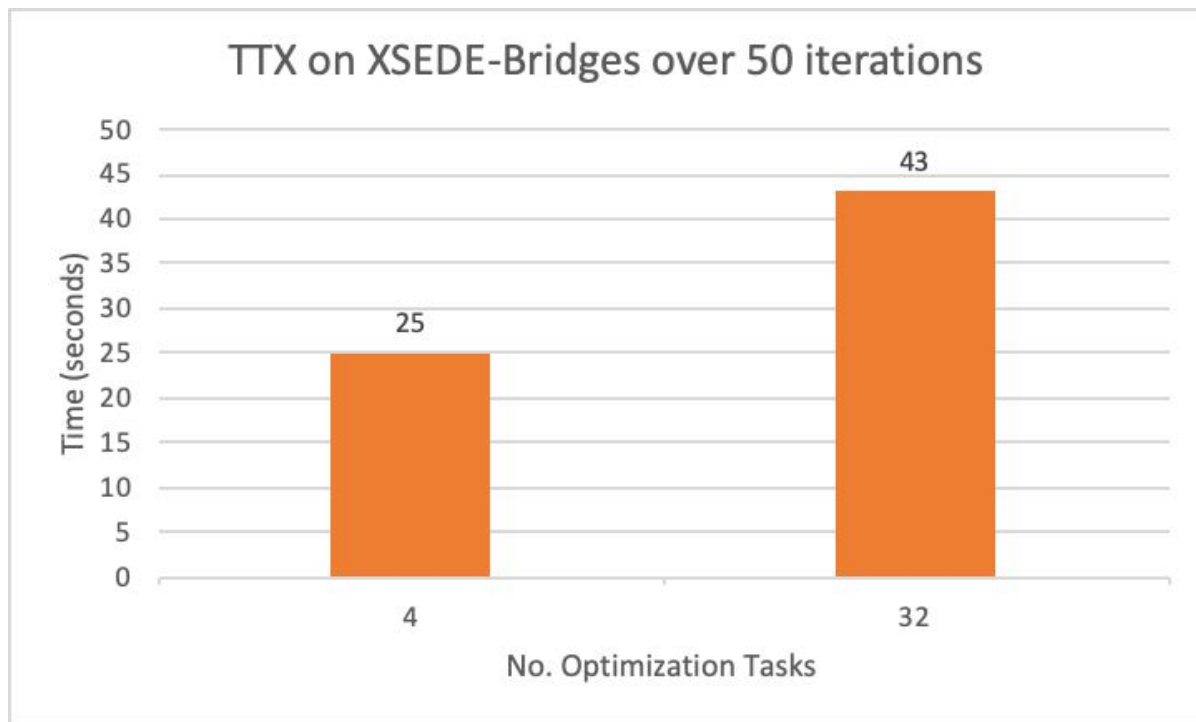
ML Example: Gradient Boosted Trees

ite-packages/scikit_optimize-0.5.2-py3.6.egg/skopt/optimizer/optimizer.py:399: UserWarning: The objective has been evaluated at this point before. warnings.warn("The objective has been evaluated " /home/karahbit/miniconda3/envs/radical.hpo/lib/python3.6/s ite-packages/scikit_optimize-0.5.2-py3.6.egg/skopt/optimizer/optimizer.py:399: UserWarning: The objective has been evaluated at this point before. warnings.warn("The objective has been evaluated " /home/karahbit/miniconda3/envs/radical.hpo/lib/python3.6/s ite-packages/scikit_learn-0.21.3-py3.6-linux-x86_64.egg/sklearn/externals/joblib/_init_.py:15: DeprecationWarning: sklearn.externals.joblib is deprecated in 0.21 and will be removed in 0.23. Please import this functionality directly from joblib, which can be installed with: pip install joblib. If this warning is raised when loading pickled models, you may need to re-serialize those models with skikit-learn 0.21+. warnings.warn(msg, category=DeprecationWarning) /home/karahbit/miniconda3/envs/radical.hpo/lib/python3.6/s ite-packages/hyperspaces-0.3.0-py3.6.egg/hyperspace/space/skopt/space.py:173: UserWarning: Each hyperspace contains a single value. Command being timed: "mpirun -n 32 python3 gbm.py --results /home/karahbit/results/gbm.py User time (seconds): 0.01 System time (seconds): 0.03 Percent of CPU this job got: 0% Elapsed (wall clock) time (h:mm:ss or m:ss): 0:42. 49 Average shared text size (kbytes): 0 Average unshared data size (kbytes): 0 Average stack size (kbytes): 0 Average total size (kbytes): 0 Maximum resident set size (kbytes): 5260 Average resident set size (kbytes): 0 Major (requiring I/O) page faults: 0 Minor (reclaiming a frame) page faults: 4487 Voluntary context switches: 248 Involuntary context switches: 64 Swaps: 0 File system inputs: 0 File system outputs: 0 Socket messages sent: 0 Socket messages received: 0 Signals delivered: 0 Page size (bytes): 4096 Exit status: 0 (radical.hpo) [karahbit@r507 examples]\$ /usr/bin/time -v mpirun -n 32 python3 gbm.py --results /home/karahbit/results/gbm	1 [100.0] 8 [100.0] 15 [100.0] 22 [100.0] 2 [100.0] 9 [100.0] 16 [100.0] 23 [0.0] 3 [100.0] 10 [100.0] 17 [0.0] 24 [0.0] 4 [100.0] 11 [100.0] 18 [0.0] 25 [0.0] 5 [100.0] 12 [100.0] 19 [0.0] 26 [0.0] 6 [100.0] 13 [100.0] 20 [0.0] 27 [0.0] 7 [100.0] 14 [100.0] 21 [0.0] 28 [0.0] Mem[] 5.12G/126G Tasks: 78, 113 thr: 17 running Swp[] 114M/16.8G Load average: 5.42 9.04 10.71 Uptime: 21 days, 14:28:17	1 [100.0] 8 [100.0] 15 [100.0] 22 [100.0] 2 [100.0] 9 [100.0] 16 [4.5] 23 [0.0] 3 [100.0] 10 [100.0] 17 [0.0] 24 [100.0] 4 [100.0] 11 [100.0] 18 [0.0] 25 [0.0] 5 [100.0] 12 [100.0] 19 [0.0] 26 [0.0] 6 [100.0] 13 [100.0] 20 [0.0] 27 [0.0] 7 [100.0] 14 [100.0] 21 [0.0] 28 [0.0] Mem[] 4.99G/126G Tasks: 74, 100 thr: 18 running Swp[] 60.5M/16.8G Load average: 5.45 9.04 11.07 Uptime: 21 days, 14:28:16
PID USER PRI NI VIRT RES SHR S CPU% MEM% TI	PID USER PRI NI VIRT RES SHR S CPU% MEM% TI	PID USER PRI NI VIRT RES SHR S CPU% MEM% TI
21005 karahbit 20 0 33.4G 152M 41760 R 100.0 0.1 0.0	27859 karahbit 20 0 33.4G 153M 41760 R 100.0 0.1 0.0	27859 karahbit 20 0 33.4G 153M 41760 R 100.0 0.1 0.0
21008 karahbit 20 0 33.4G 153M 41772 R 100.0 0.1 0.0	27870 karahbit 20 0 33.4G 146M 41724 R 100.0 0.1 0.0	27870 karahbit 20 0 33.4G 146M 41724 R 100.0 0.1 0.0
20999 karahbit 20 0 33.4G 149M 41772 R 100.0 0.1 0.0	27866 karahbit 20 0 33.4G 148M 41716 R 100.0 0.1 0.0	27866 karahbit 20 0 33.4G 148M 41716 R 100.0 0.1 0.0
21006 karahbit 20 0 33.4G 149M 41760 R 100.0 0.1 0.0	27861 karahbit 20 0 33.4G 155M 41760 R 100.0 0.1 0.0	27861 karahbit 20 0 33.4G 155M 41760 R 100.0 0.1 0.0
21009 karahbit 20 0 33.4G 155M 41764 R 100.0 0.1 0.0	27865 karahbit 20 0 33.4G 153M 41760 R 100.0 0.1 0.0	27865 karahbit 20 0 33.4G 153M 41760 R 100.0 0.1 0.0
21000 karahbit 20 0 33.4G 149M 41760 R 100.0 0.1 0.0	27874 karahbit 20 0 33.4G 148M 41716 R 100.0 0.1 0.0	27874 karahbit 20 0 33.4G 148M 41716 R 100.0 0.1 0.0
21010 karahbit 20 0 33.4G 149M 41760 R 100.0 0.1 0.0	27862 karahbit 20 0 33.4G 148M 41728 R 100.0 0.1 0.0	27862 karahbit 20 0 33.4G 148M 41728 R 100.0 0.1 0.0
21001 karahbit 20 0 33.4G 149M 41760 R 99.6 0.1 0.0	27869 karahbit 20 0 33.4G 155M 41760 R 100.0 0.1 0.0	27869 karahbit 20 0 33.4G 155M 41760 R 100.0 0.1 0.0
21011 karahbit 20 0 33.4G 149M 41768 R 99.6 0.1 0.0	27871 karahbit 20 0 33.4G 150M 41620 R 100.0 0.1 0.0	27871 karahbit 20 0 33.4G 150M 41620 R 100.0 0.1 0.0
20996 karahbit 20 0 33.4G 149M 41764 R 99.6 0.1 0.0	27864 karahbit 20 0 33.4G 146M 41716 R 99.5 0.1 0.0	27864 karahbit 20 0 33.4G 146M 41716 R 99.5 0.1 0.0
20997 karahbit 20 0 33.4G 148M 41728 R 99.6 0.1 0.0	27863 karahbit 20 0 33.4G 153M 41760 R 99.5 0.1 0.0	27863 karahbit 20 0 33.4G 153M 41760 R 99.5 0.1 0.0
21002 karahbit 20 0 33.4G 149M 41764 R 99.6 0.1 0.0	27857 karahbit 20 0 33.4G 146M 41692 R 99.5 0.1 0.0	27857 karahbit 20 0 33.4G 146M 41692 R 99.5 0.1 0.0
21003 karahbit 20 0 33.4G 149M 41764 R 99.6 0.1 0.0	27872 karahbit 20 0 33.4G 148M 41628 R 99.5 0.1 0.0	27872 karahbit 20 0 33.4G 148M 41628 R 99.5 0.1 0.0
21004 karahbit 20 0 33.4G 149M 41728 R 99.6 0.1 0.0	27868 karahbit 20 0 33.4G 147M 41764 R 99.5 0.1 0.0	27868 karahbit 20 0 33.4G 147M 41764 R 99.5 0.1 0.0
21007 karahbit 20 0 33.4G 149M 41760 R 99.6 0.1 0.0	27873 karahbit 20 0 33.4G 148M 41716 R 99.5 0.1 0.0	27873 karahbit 20 0 33.4G 148M 41716 R 99.5 0.1 0.0
20998 karahbit 20 0 33.4G 151M 41760 R 99.6 0.1 0.0	27860 karahbit 20 0 33.4G 148M 41748 R 98.8 0.1 0.0	27860 karahbit 20 0 33.4G 148M 41748 R 98.8 0.1 0.0
14714 karahbit 20 0 120M 2532 1464 R 1.3 0.0 0.2	21111 karahbit 20 0 120M 2396 1460 R 2.0 0.0 0.2	21111 karahbit 20 0 120M 2396 1460 R 2.0 0.0 0.2
20984 root 20 0 203M 3436 2516 S 0.0 0.0 0.0	7750 pcp 20 0 106M 4884 3032 S 0.7 0.0 5.3	7750 pcp 20 0 106M 4884 3032 S 0.7 0.0 5.3
20991 karahbit 20 0 16716 1688 1336 S 0.0 0.0 0.0	27847 root 20 0 204M 3440 2516 S 0.0 0.0 0.0	27847 root 20 0 204M 3440 2516 S 0.0 0.0 0.0
5799 munge 20 0 734M 1876 1524 S 0.0 0.0 0.1	7747 pcp 20 0 106M 4884 3032 S 0.0 0.0 8.4	7747 pcp 20 0 106M 4884 3032 S 0.0 0.0 8.4
20974 karahbit 20 0 14964 1736 1388 S 0.0 0.0 0.0	2078 root 20 0 3388M 56860 10000 S 0.0 0.0 0.0	2078 root 20 0 3388M 56860 10000 S 0.0 0.0 0.0
20975 karahbit 20 0 308M 5124 2072 S 0.0 0.0 0.0	27853 karahbit 20 0 16716 1644 1284 S 0.0 0.0 0.0	27853 karahbit 20 0 16716 1644 1284 S 0.0 0.0 0.0
6139 root 20 0 1198M 968M 3020 S 0.0 0.0 4.0	24776 root 20 0 624M 503M 2328 S 0.0 0.0 1.3	24776 root 20 0 624M 503M 2328 S 0.0 0.0 1.3
14429 root 20 0 266M 3224 2428 S 0.0 0.0 0.0	2741 root 20 0 379M 7486M 8644 S 0.0 0.1 2.2	2741 root 20 0 379M 7486M 8644 S 0.0 0.1 2.2
28231 root 20 0 378M 75424 8636 S 0.0 0.1 2.2	21839 root 20 0 267M 3224 2428 S 0.0 0.0 0.0	21839 root 20 0 267M 3224 2428 S 0.0 0.0 0.0
26260 pcp 20 0 94916 4348 2436 S 0.0 0.0 0.0	1 root 20 0 187M 4792 2616 S 0.0 0.0 8.1	1 root 20 0 187M 4792 2616 S 0.0 0.0 8.1
14430 root 20 0 266M 3224 2428 S 0.0 0.0 0.0	18764 root 20 0 21768 1428 996 S 0.0 0.0 6.1	18764 root 20 0 21768 1428 996 S 0.0 0.0 6.1
6225 root 20 0 413M 3560 720 S 0.0 0.0 1.1	5820 root 20 0 561M 19652 6316 S 0.0 0.0 2.5	5820 root 20 0 561M 19652 6316 S 0.0 0.0 2.5
6223 root 20 0 413M 3560 720 S 0.0 0.0 4.1	7751 root 20 0 203M 5700 3452 S 0.0 0.0 1.0	7751 root 20 0 203M 5700 3452 S 0.0 0.0 1.0
8553 root 20 0 21768 1412 992 S 0.0 0.0 6.1	6276 root 20 0 413M 3704 776 S 0.0 0.0 5.0	6276 root 20 0 413M 3704 776 S 0.0 0.0 5.0
6146 root 20 0 93532 1572 1428 S 0.0 0.0 1.4	5996 root 20 0 561M 19652 6316 S 0.0 0.0 2.5	5996 root 20 0 561M 19652 6316 S 0.0 0.0 2.5
14436 root 20 0 333M 3792 2612 S 0.0 0.0 0.0	5233 root 20 0 27656 1972 1484 S 0.0 0.0 0.3	5233 root 20 0 27656 1972 1484 S 0.0 0.0 0.3
1 root 20 0 187M 4228 2408 S 0.0 0.1 7.4	5740 munge 20 0 735M 2392 1922 S 0.0 0.0 0.1	5740 munge 20 0 735M 2392 1922 S 0.0 0.0 0.1
32413 root 20 0 295M 69428 9984 S 0.0 0.1 0.2	24019 root 16 -0 51972 8512 2966 S 0.0 0.0 0.1	24019 root 16 -0 51972 8512 2966 S 0.0 0.0 0.1
5749 root 20 0 560M 12028 2152 S 0.0 0.0 2.4	2823 root 20 0 6376M 25712 25366 S 0.0 0.0 0.5	2823 root 20 0 6376M 25712 25366 S 0.0 0.0 0.5
26222 root 20 0 3379M 56300 8920 S 0.0 0.0 0.0	5863 root 20 0 405M 124M 1484 S 0.0 0.1 1.3	5863 root 20 0 405M 124M 1484 S 0.0 0.1 1.3
5802 munge 20 0 734M 1876 1524 S 0.0 0.0 0.0	16228 nsld 20 0 449M 6000 3492 S 0.0 0.0 0.3	16228 nsld 20 0 449M 6000 3492 S 0.0 0.0 0.3
5811 munge 20 0 734M 1876 1524 S 0.0 0.0 0.0	4754 root 20 0 10644 616 488 S 0.0 0.0 0.4	4754 root 20 0 10644 616 488 S 0.0 0.0 0.4
2830 root 20 0 71952 28108 27760 S 0.0 0.0 0.5	21841 root 20 0 267M 3224 2428 S 0.0 0.0 0.0	21841 root 20 0 267M 3224 2428 S 0.0 0.0 0.0

ML Example: Gradient Boosted Trees



TTX on XSEDE-Bridges over 50 iterations



References

<https://scikit-optimize.github.io>

<https://examples.dask.org/machine-learning/hyperparam-opt.html>

<https://towardsdatascience.com/hyperparameter-optimization-in-python-part-0-introduction-c4b66791614b>

<https://github.com/jdakka/hyperspace-RCT>

<https://github.com/yngtodd/hyperspace>

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