Sawmill: From Logs to Causal Diagnosis of Large Systems

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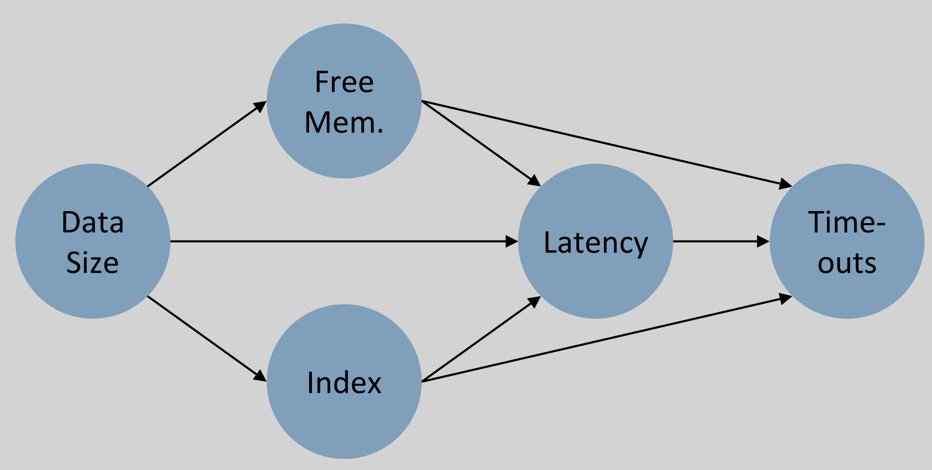
Causal Analysis on Logs Faces 3 Key Challenges

```
20:24:44 INFO u0 q34 Running CREATE INDEX midx ON metrics (id);
20:32:25 INFO u0 q35 Running SELECT * FROM metrics WHERE id=562;
20:32:26 INFO u0 q35 Ran in 607.31ms
20:32:28 INFO u0 q36 Running SELECT * FROM metrics WHERE id=555;
20:33:28 INFO u0 q36 Query timed out
```

User	M: Free Memory	I:Index Presence	L:Latency Mean (ms)	D: Data Size (GB)	T: Timeouts per day
U_0	67.80 %	1	637.02	64.41	56852
U_1	80.96 %	0	372.60	38.07	29164
...	...	...	...	...	...



Causal Analysis Can Help System Understanding

- Failures are a daily phenomenon when operating large complex systems.
- Diagnosing system problems quickly and correctly is crucial for operators.
- Causal reasoning [1] has helped scientists across domains pose, discuss and test hypotheses.

Applying Causality to Log Data is Challenging

- Pearl's framework [1] requires tabular data and a causal graph for the problem.
- However, operators often only have access to textual logs.
- Three key challenges:
  - **Challenge A – Deriving the Schema:** Logs can be parsed, but this can lead to hundreds of unlabeled variables that are hard for a human to manually label.
  - **Challenge B – Distilling the Data:** Logs contain a lot of fine-grained data. What is the best way to summarize it along the units the user cares about (e.g. machines)?
  - **Challenge C – Obtaining the Causal Graph:** The scale and dependencies in log data make automatic causal discovery [2,3] challenging. Can we tap the user's expertise intelligently?

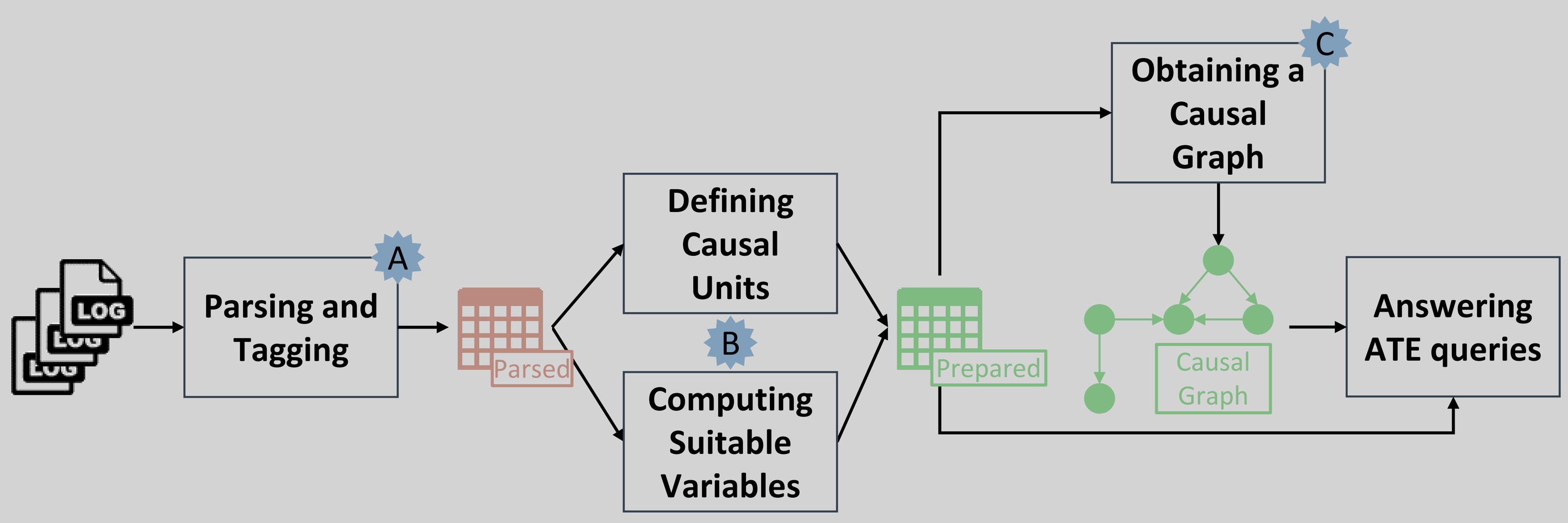
Sawmill Provides Solutions for Each Challenge

Challenge A: Utilize LLMs for Tagging

- Use Drain [4] to create the unlabeled *parsed table.*
- Leverage GPT-4 [5] to assign human-understandable tags to each variable.

Challenge B: Aggregate Data to Maximize Entropy

- Log information can be too granular for meaningful analysis.
- Users can define **causal units** over which to aggregate log information, depending on the context (e.g. machines, users etc.).
- The best aggregate to pick for each variable can be unclear a priori.
- We pick the aggregate that **maximizes empirical entropy** between the causal units, in order to maximize downstream usefulness.



Challenge C: Leverage Exploration-based Causal Discovery

- Algorithmic causal discovery faces challenges due to dependencies.
- Hand-crafting a full causal model is also daunting, but only part of it is needed.
- Use a human in the loop:
  - User provides a **variable of interest.**
  - Sawmill suggests **candidate causes.**
  - User evaluates them and revises graph.
  - The process repeats while increasing the **exploration score.**

With a Handful of User Interactions, Sawmill Uncovers Highly Accurate Effects

Dataset			True ATE	Sawmill ATE	Regression ATE	AskGPT ATE
D2 Proprietary	F=0.5	p_f=1.0	258.43	**257.47**	273.01	0.00
		p_f=0.5	114.86	**112.66**	118.04	112.66
		p_f=0.2	28.71	**27.28**	25.94	27.28
	F=0.1	p_f=1.0	258.43	**258.64**	256.01	0.00
		p_f=0.5	114.86	121.45	**119.38**	0.00
		p_f=0.2	28.71	**33.98**	35.30	0.00
	F=0.01	p_f=1.0	258.43	**258.57**	264.50	258.57
		p_f=0.5	114.86	**85.66**	84.79	0.0
		p_f=0.2	28.71	**42.64**	45.18	0.0
D3 XYZ	V=10	R=1	2.00	**2.00**	2.00	2.00
		R=5	2.00	2.11	**2.10**	2.11
		R=10	2.00	1.97	**1.98**	1.97
	V=100	R=1	2.00	**1.96**	1.95	2.36
		R=5	2.00	**1.60**	1.58	0.00
		R=10	2.00	0.87	0.86	**0.97**
	V=1000	R=1	2.00	**1.78**	0.37	0.00
		R=5	2.00	**0.62**	-1.61	0.62
		R=10	2.00	0.12	**0.35**	0.00
Mean % Error on Proprietary				**11.72%**	14.64%	67.44%
Mean % Error on XYZ				**28.83%**	47.88%	49.50%
Mean % Error				**20.27%**	31.26%	58.47%

Dataset			Sawmill MRR	Regression MRR	AskGPT MRR
D1 PostgreSQL			**0.5667**	0.0476	0.4815
D2 Proprietary	F=0.5	p_f=1.0	**1.0000**	1.0000	0.0000
		p_f=0.5	**1.0000**	1.0000	0.3333
		p_f=0.2	**1.0000**	1.0000	1.0000
	F=0.1	p_f=1.0	**1.0000**	1.0000	0.0000
		p_f=0.5	**1.0000**	1.0000	0.0000
		p_f=0.2	**1.0000**	1.0000	0.0000
	F=0.01	p_f=1.0	**1.0000**	1.0000	0.0714
		p_f=0.5	**1.0000**	0.0667	0.0000
		p_f=0.2	**1.0000**	0.0667	0.0000
D3 XYZ	V=10	R=1	**0.6667**	0.6667	0.4007
		R=5	0.6111	0.5556	**0.6667**
		R=10	**0.6667**	0.5833	0.0664
	V=100	R=1	**0.6667**	0.5476	0.5000
		R=5	**0.6667**	0.5370	0.0000
		R=10	0.3889	**0.6667**	0.5000
	V=1000	R=1	**0.6667**	0.0000	0.1667
		R=5	0.6667	0.0000	**0.8333**
		R=10	**0.6667**	0.0000	0.1667
Mean on Proprietary			**1.0000**	0.7926	0.1561
Mean on XYZ			**0.6296**	0.3952	0.3667
Mean			**0.8018**	0.5651	0.2730

Dataset			Parse (s)	Prepare (s)	ExploreCandidateCauses (s)	**Total Time (s)**	Total Time over Log Size (s/MiB)
D1 PostgreSQL			37.65	4.41	4.85	46.91	2.39
D2 Proprietary	F=0.5	p_f=1.0	189.19	48.58	2.62	240.39	1.06
		p_f=0.5	189.51	48.83	3.20	241.54	1.07
		p_f=0.2	195.58	49.32	3.18	248.08	1.10
	F=0.1	p_f=1.0	194.50	49.11	3.22	246.83	1.09
		p_f=0.5	189.53	49.18	3.24	241.95	1.07
		p_f=0.2	189.58	49.50	3.28	242.36	1.07
	F=0.01	p_f=1.0	190.70	49.99	3.31	244.00	1.08
		p_f=0.5	187.09	49.47	3.38	239.94	1.06
		p_f=0.2	191.18	49.30	3.43	243.91	1.08
D3 XYZ	V=10	R=1	72.33	4.26	2.40	78.99	1.32
		R=5	80.04	5.27	2.98	88.29	1.48
		R=10	79.69	4.70	3.09	87.48	1.47
	V=100	R=1	145.67	33.24	3.59	182.50	2.95
		R=5	144.14	33.87	3.87	181.88	2.94
		R=10	144.67	33.79	3.97	182.43	2.95
	V=1000	R=1	853.14	326.83	8.38	1188.35	18.90
		R=5	822.43	334.47	8.91	1165.81	18.54
		R=10	849.08	335.59	15.09	1199.76	19.08
Mean			260.30	82.09	4.53	346.92	4.30
Breakdown (%)			75.03%	23.66%	1.30%		

Dataset	System	Parse	Separate	SetCausalUnit	Prepare	Explore CandidateCauses	Accept	GetATE	Regress	GPT-Explore CandidateCauses	**Total**
D1 PostgreSQL	Sawmill	1	1	1	1	2	3	1	0	0	10
	Regression	1	1	1	1	0	0	0	1	0	**5**
	AskGPT	1	1	1	1	0	3	1	0	2	10
D2 Proprietary	Sawmill	1	0	1	1	1	1	1	0	0	6
	Regression	1	0	1	1	0	0	0	1	0	**4**
	AskGPT	1	0	1	1	0	1	1	0	1	6
D3 XYZ	Sawmill	1	0	1	1	2	3	1	0	0	9
	Regression	1	0	1	1	0	0	0	1	0	**4**
	AskGPT	1	0	1	1	0	3	1	0	2	9

D1 Battling Confounding in Real-World Logs

- Collect logs from **PostgreSQL running TPC-DS**.
- **Vary performance-affecting parameters** and **bias parameter combinations** to trade off work_mem and max_parallel_workers.
- Ignoring bias makes **mean latency increase for more parallelism.**

D2 Discerning Subtle Semi-Synthetic Effects

- Start with **real logs from a mobile application** and generate similar logs for 1000 users. Label a varying fraction of them (1% to 50%) as **faulty.**
- Have faulty users artificially be on a **different OS version** and have them **fail HTTP requests at varying rates** (20% to 100% of the time).
- Have non-faulty users **fail HTTP requests 10% of the time.**

D3 Overcoming Noisiness in Synthetic Logs

- Generate synthetic logs for each of 1000 "machines" with a **varying number of variables (V in 10-1000).**
- Have most of the variables take a **random value between 0-100.**
- Set special variables x,y,z such that **z confounds the effect of x on y.**
- Add Gaussian noise to x and y, with a **varying standard deviation (1-10).**

[1] Judea Pearl. 2009. Causality: Models, Reasoning and Inference. Cambridge University Press.
[2] Clark Glymour, Kun Zhang, and Peter Spirtes. 2019. Review of causal discovery methods based on graphical models. Frontiers in genetics 10 (2019), 524
[3] Peter Spirtes, Clark N Glymour, and Richard Scheines. 2000. Causation, prediction, and search. MIT press
[4] Pinjia He, Jieming Zhu, Zibin Zheng, and Michael R. Lyu. 2017. Drain: An Online Log Parsing Approach with Fixed Depth Tree. In 2017 IEEE International Conference on Web Services (ICWS). 33–40. https://doi.org/10.1109/ICWS.2017.13
[5] OpenAI. 2023. GPT-4 Technical Report. arXiv:2303.08774 [cs.CL]