Not-so-good Vibrations:

Electric Grid Oscillations & Unearned Data Wisdom

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March 31, 2022
RVA Tech Data Summit

Dominion Energy®

Today’s Adventure

Preamble: *A (Tiny) Bit about the Grid*

Part 1: *Measuring the Grid*

Part 2: *Unearned Wisdom*

Part 3: *A Better Way?*

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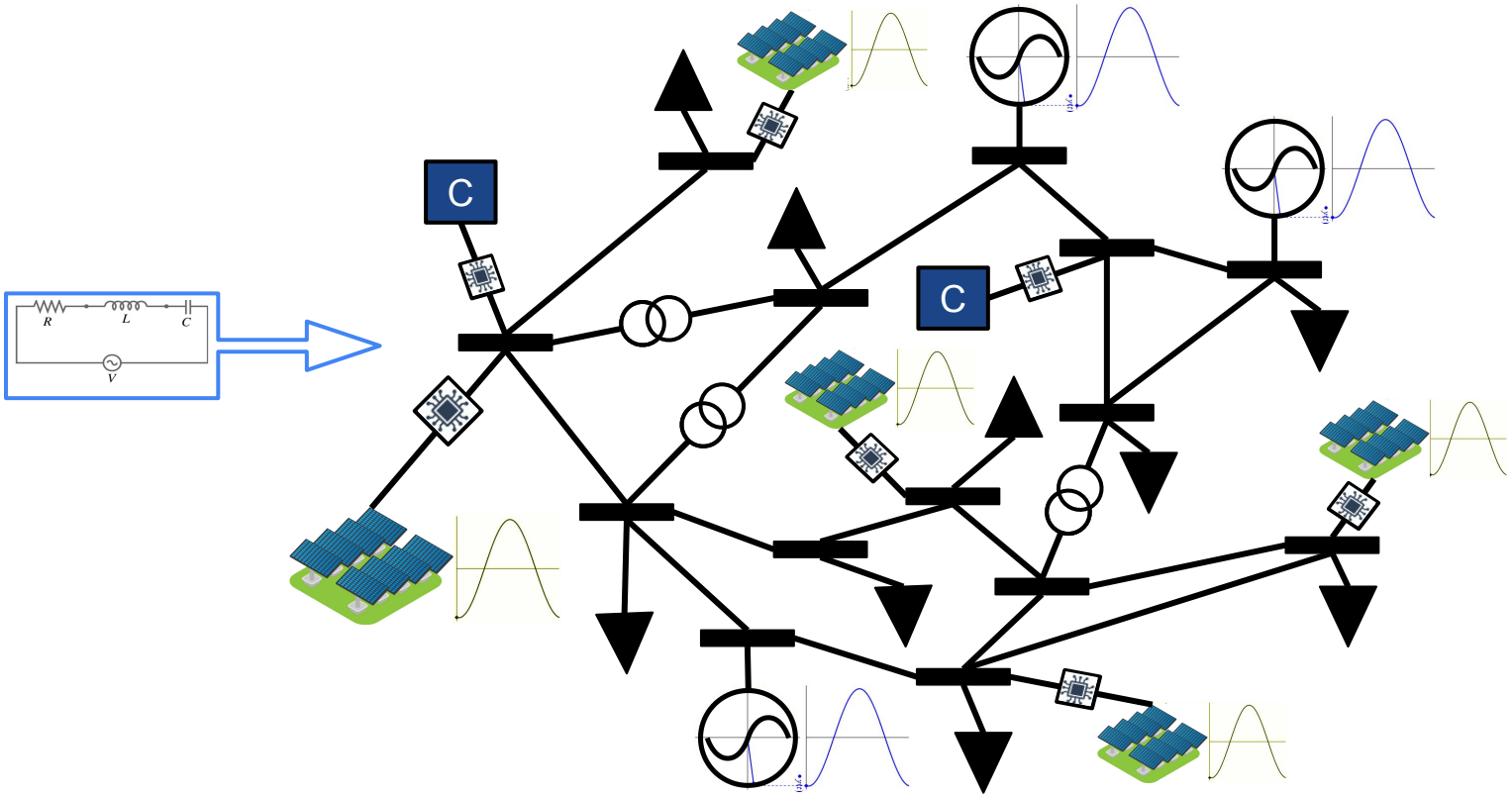
Preamble:
A Bit about the Grid

… and my team at Dominion

The Machine that Runs the Entire ~~Economy~~ World



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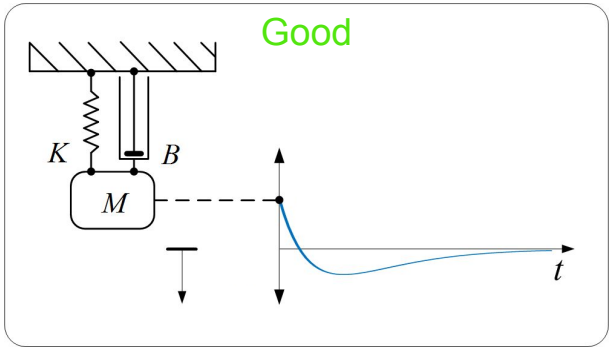
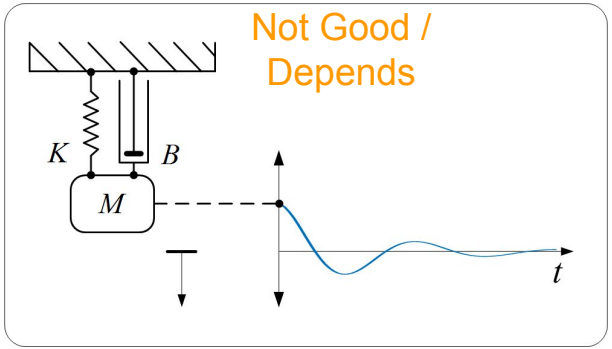
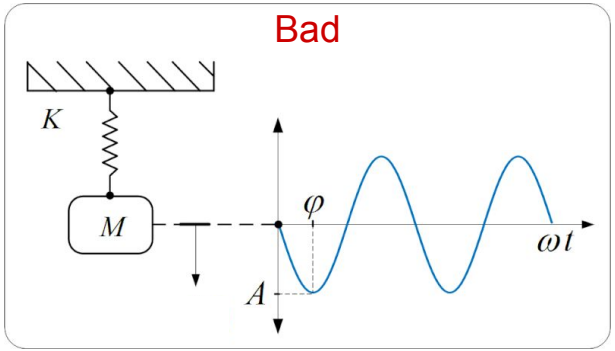
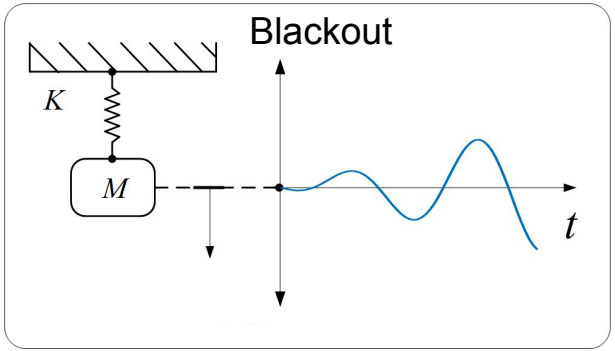
Why are Grid “Vibrations” Bad?









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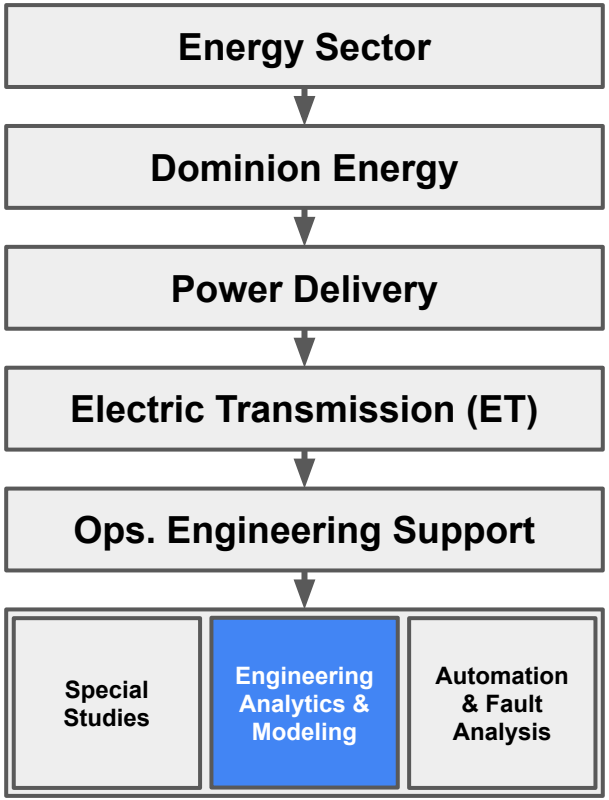
Our Team & Our Mission



What We Do…

We manage and utilize ET time-series data for R.C.A., Ops Support, Design, Asset Health, and Planning.

What We Believe…

The clean energy transition is necessarily a digital transformation and the competent use of high-resolution sensor data from the grid is critical to the cost-effective and maximal integration of renewable energy resources.

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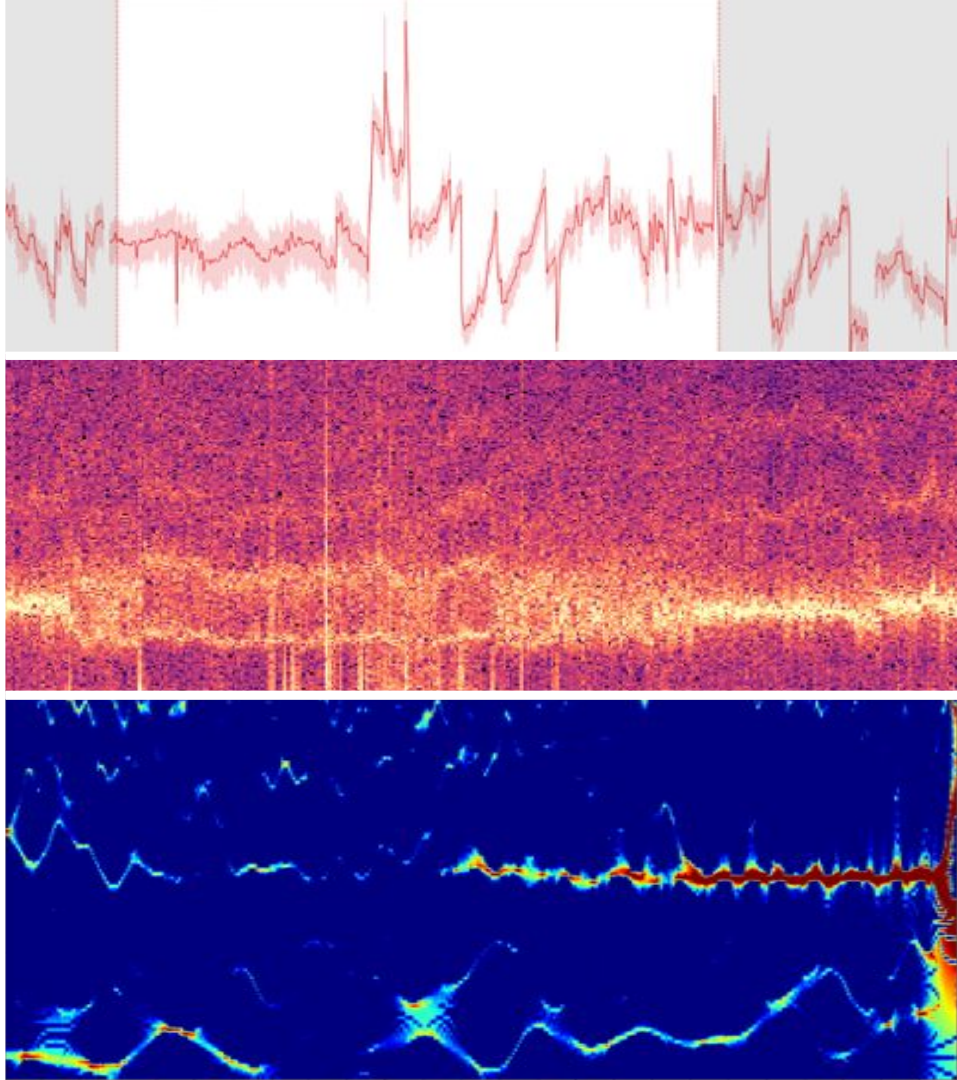
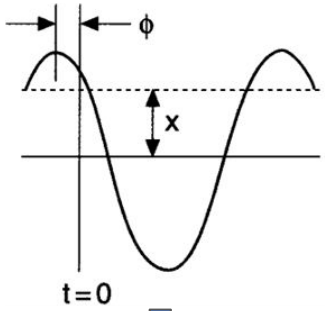
Part 1:
Measuring the Grid

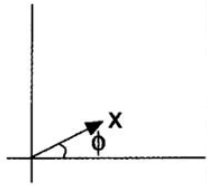
…and some cool things we can do with grid sensor data



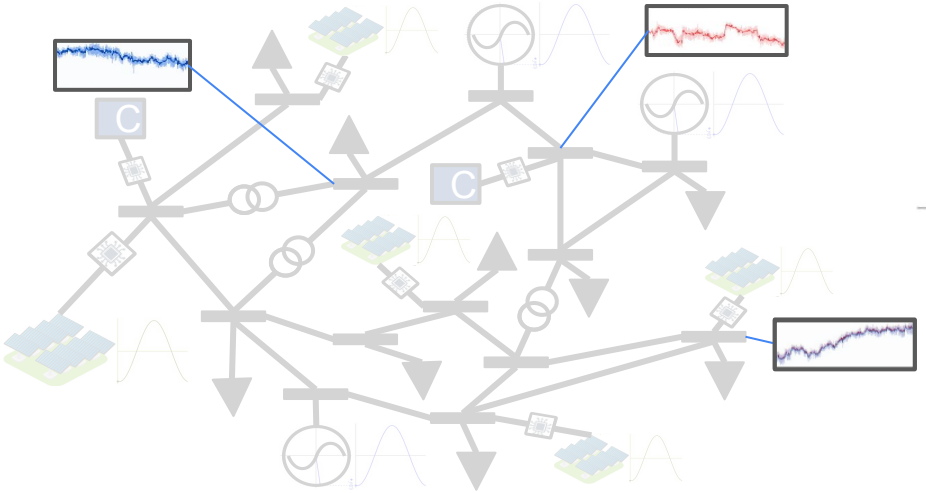
What Physical Quantities Do We Measure?

AC Voltage & Current!

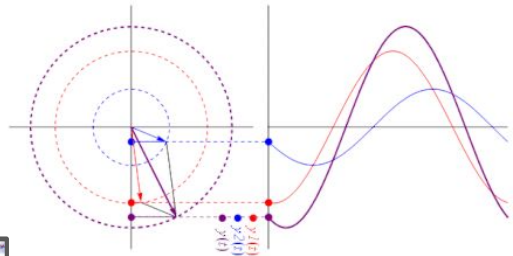




Voltage & Current Phasors!



The Wide-Area Measurement Problem



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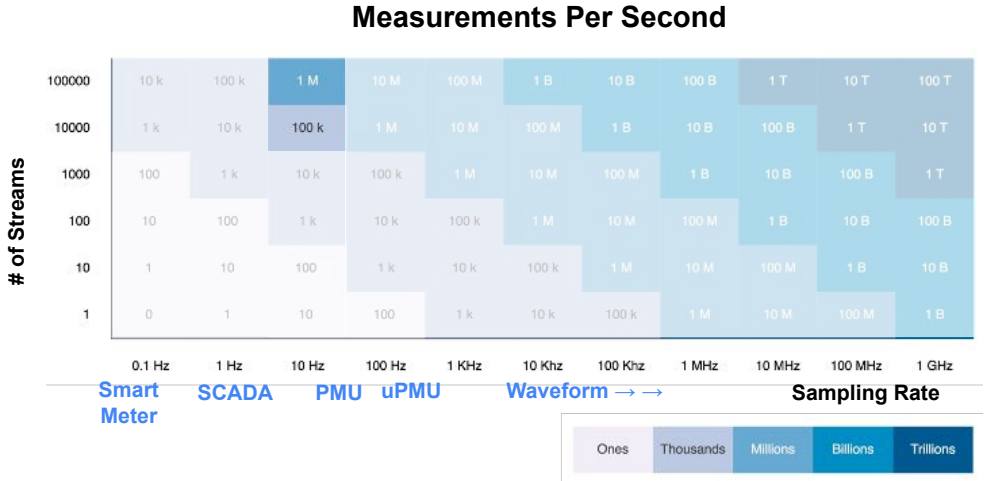
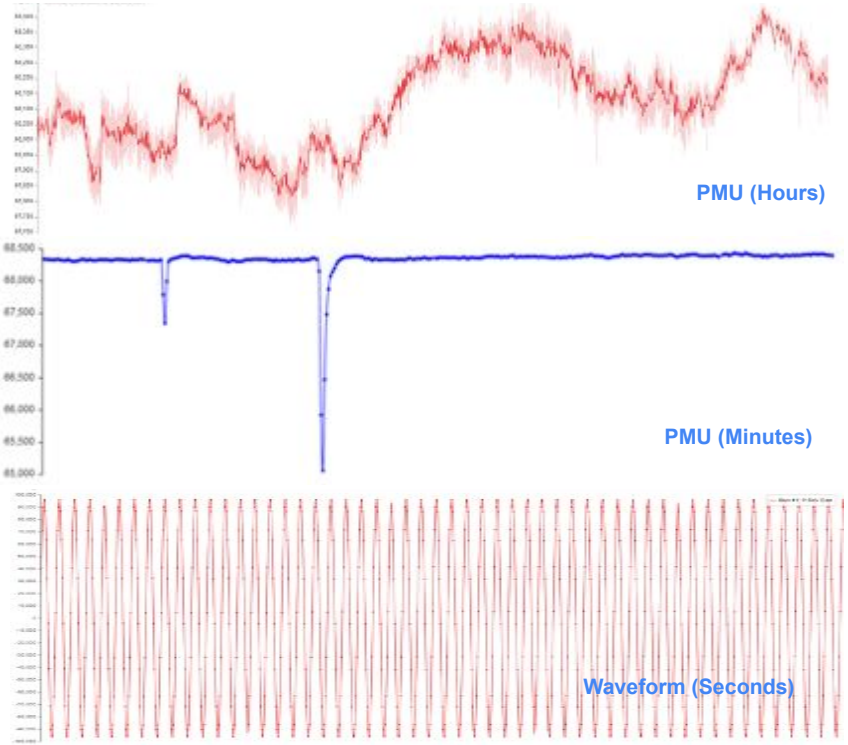
Our Data: *Physics-Based, High-Resolution Time-Series*

`(timestamp, value)`

64-bit int 64-bit float





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Our Data: *A Unique Computer Science Problem*

Volume (***Density!***) & Velocity

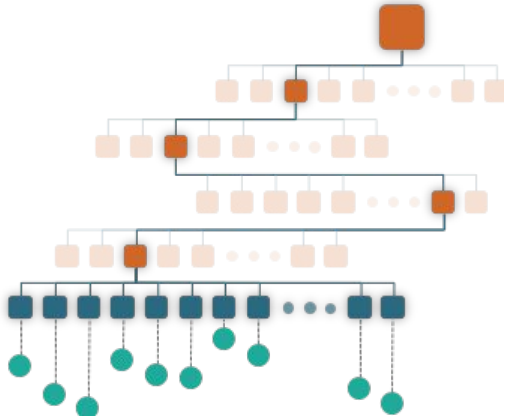
Annual Measurement Data Volume

# of Streams	0.1 Hz	1 Hz	10 Hz	100 Hz	1 KHz	10 Khz	100 Khz	1 MHz	10 MHz	100 MHz	1 GHz
100000	4.6 TB	45.9 TB	459.2 TB	4.5 PB	44.9 PB	448.5 PB	4.4 EB	43.8 EB	437.9 EB	4.3 ZB	42.8 ZB
10000	470.2 GB	4.6 TB	45.9 TB	459.2 TB	4.5 PB	44.9 PB	448.5 PB	4.4 EB	43.8 EB	437.9 EB	4.3 ZB
1000	47.0 GB	470.2 GB	4.6 TB	45.9 TB	459.2 TB	4.5 PB	44.9 PB	448.5 PB	4.4 EB	43.8 EB	437.9 EB
100	4.7 GB	47.0 GB	470.2 GB	4.6 TB	45.9 TB	459.2 TB	4.5 PB	44.9 PB	448.5 PB	4.4 EB	43.8 EB
10	481.5 MB	4.7 GB	47.0 GB	470.2 GB	4.6 TB	45.9 TB	459.2 TB	4.5 PB	44.9 PB	448.5 PB	4.4 EB
1	48.1 MB	481.5 MB	4.7 GB	47.0 GB	470.2 GB	4.6 TB	45.9 TB	459.2 TB	4.5 PB	44.9 PB	448.5 PB

Smart Meter | SCADA | PMU | uPMU | Waveform → → | Sampling Rate

Megabytes | Gigabytes | Terabytes | Petabytes | Exabytes | Zettabytes

Unique from the Bottom Up



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Our Data: *A Unique Computer Science Problem*

Human-scale data exploration: “Google Maps” for Time-Series [https://pingthings.io]

The unaltered video above shows a 120Hz signal with 1 billion measurements covering more than 3 months as a user zooms in and locates a voltage sag comprised of 7 measurements (50 milliseconds) in real-time.

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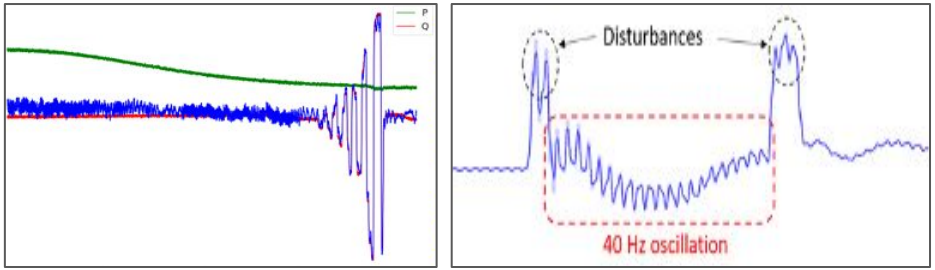
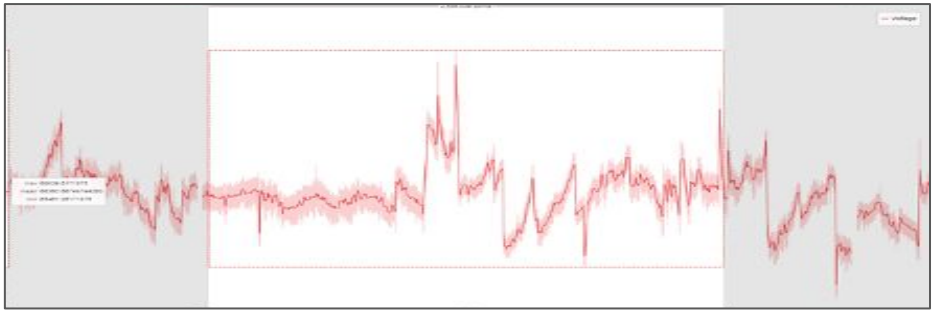
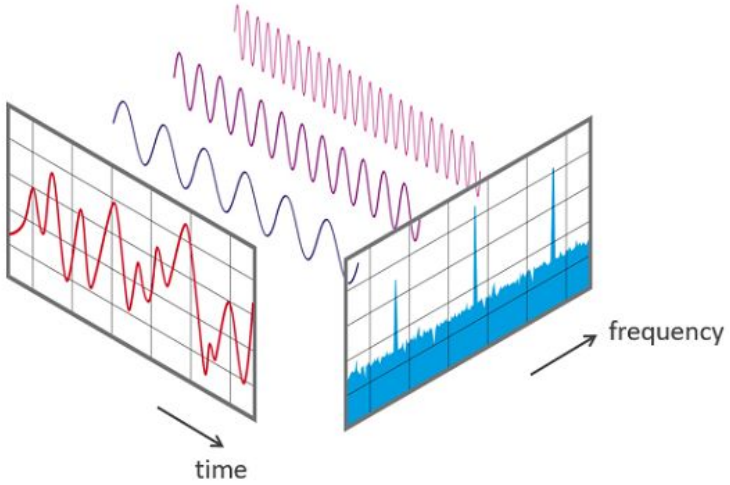
How Do We “Measure” Vibrations?



Events are great, but rare…



“Ambient” data is rich and underrated!



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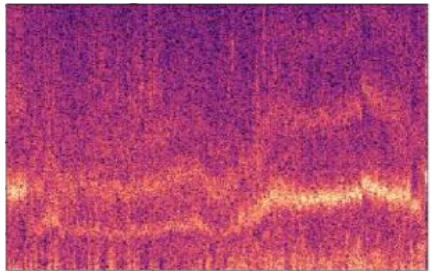
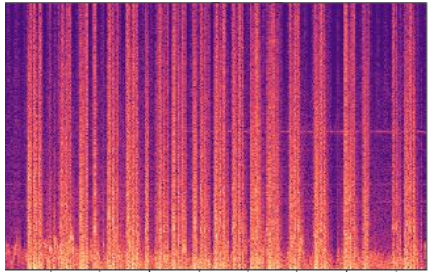
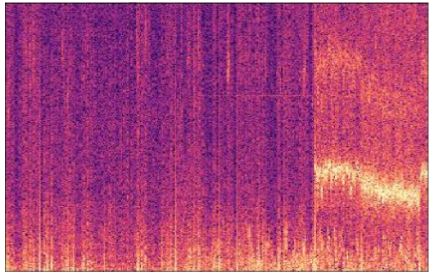
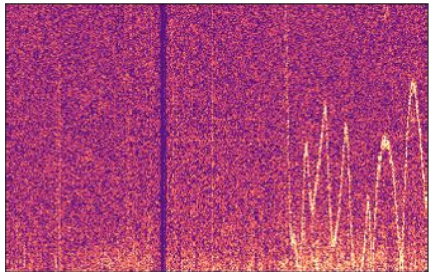
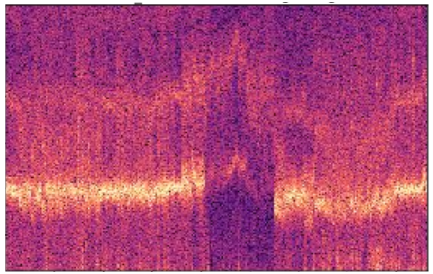
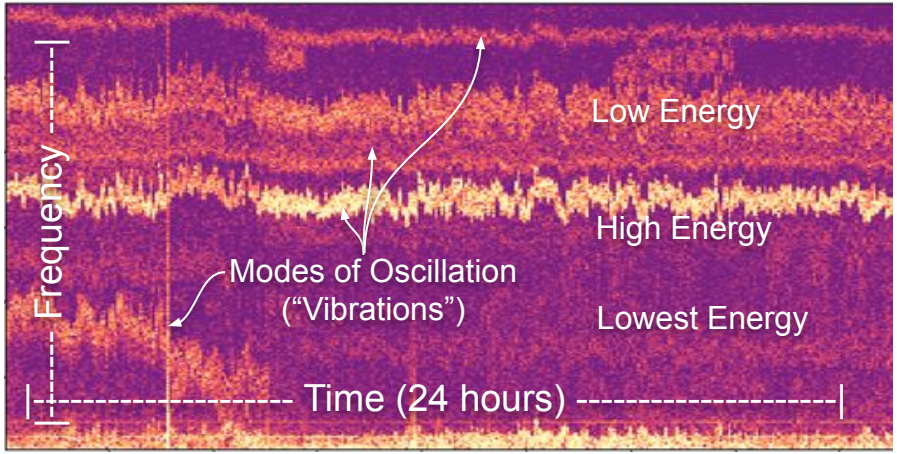


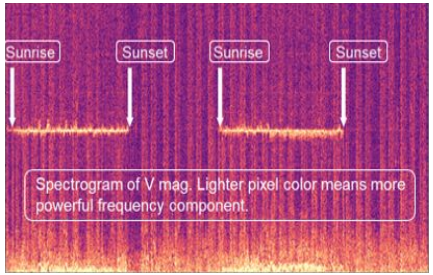


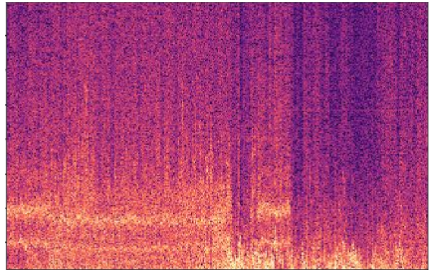


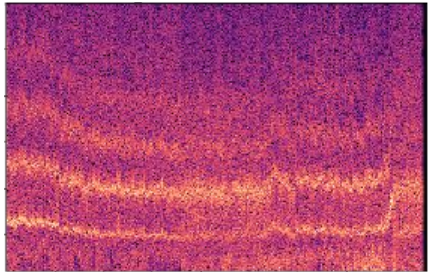


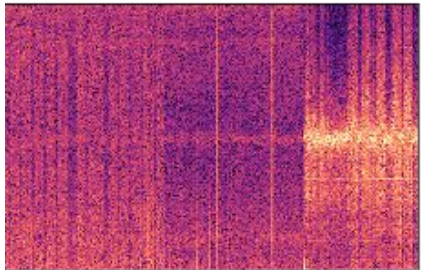


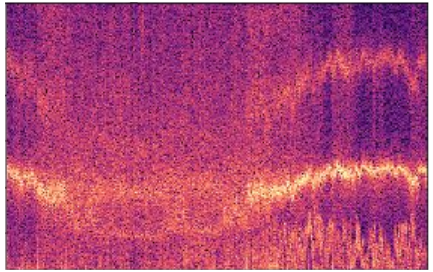

Frequency
Low Energy
High Energy
Lowest Energy
Modes of Oscillation
("Vibrations")
Time (24 hours)


Sunrise
Sunset
Sunrise
Sunset
Spectrogram of V mag. Lighter pixel color means more powerful frequency component.

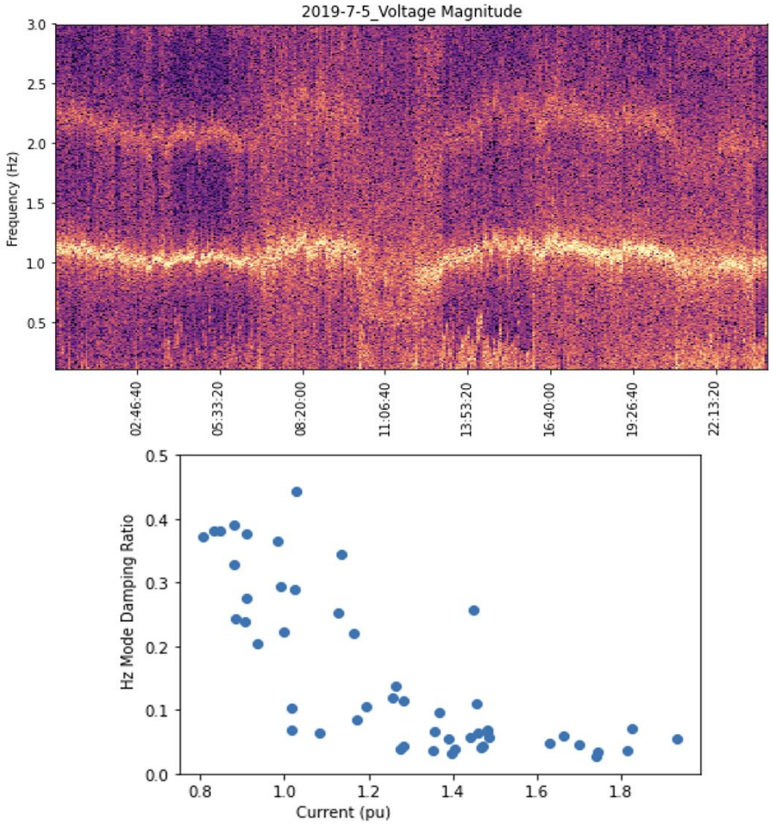


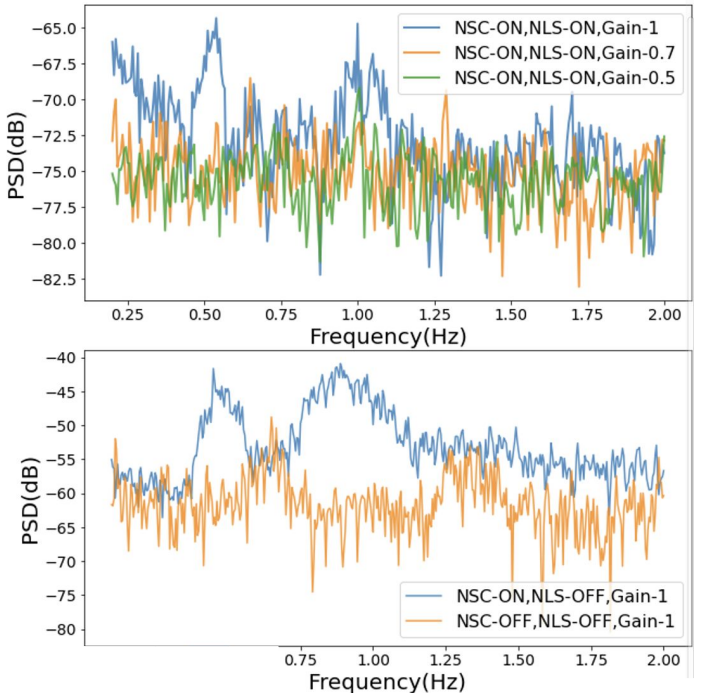






Example 1: What's Broken?





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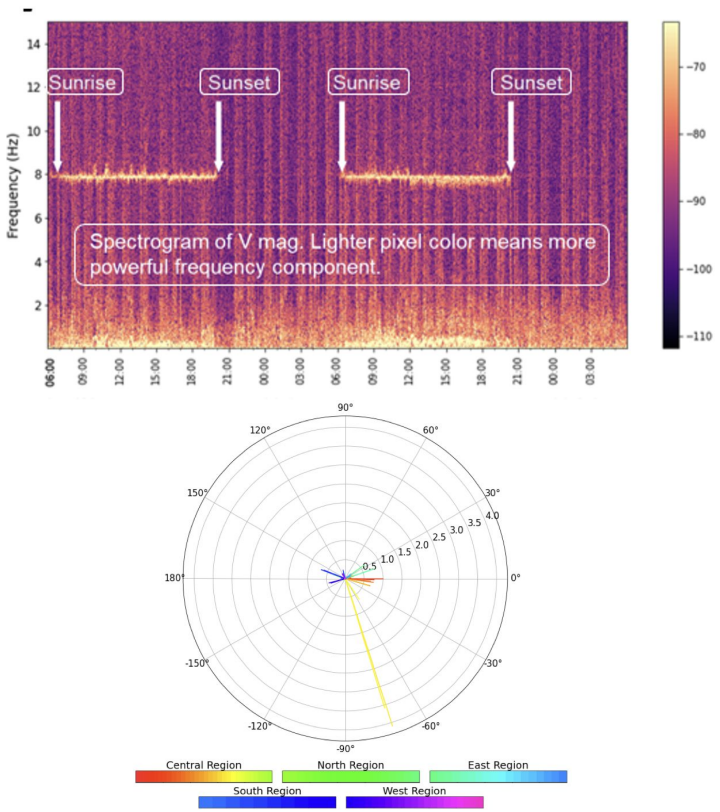
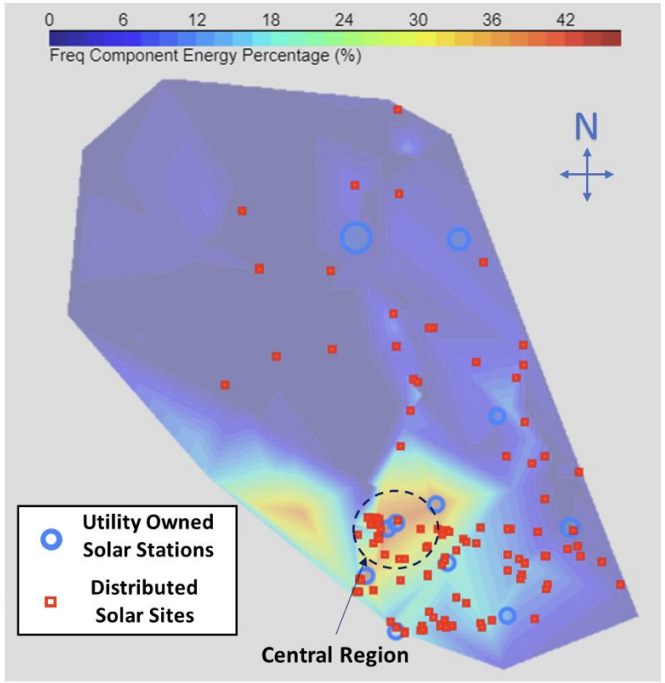
Example 2: How Big of a Deal Is It?





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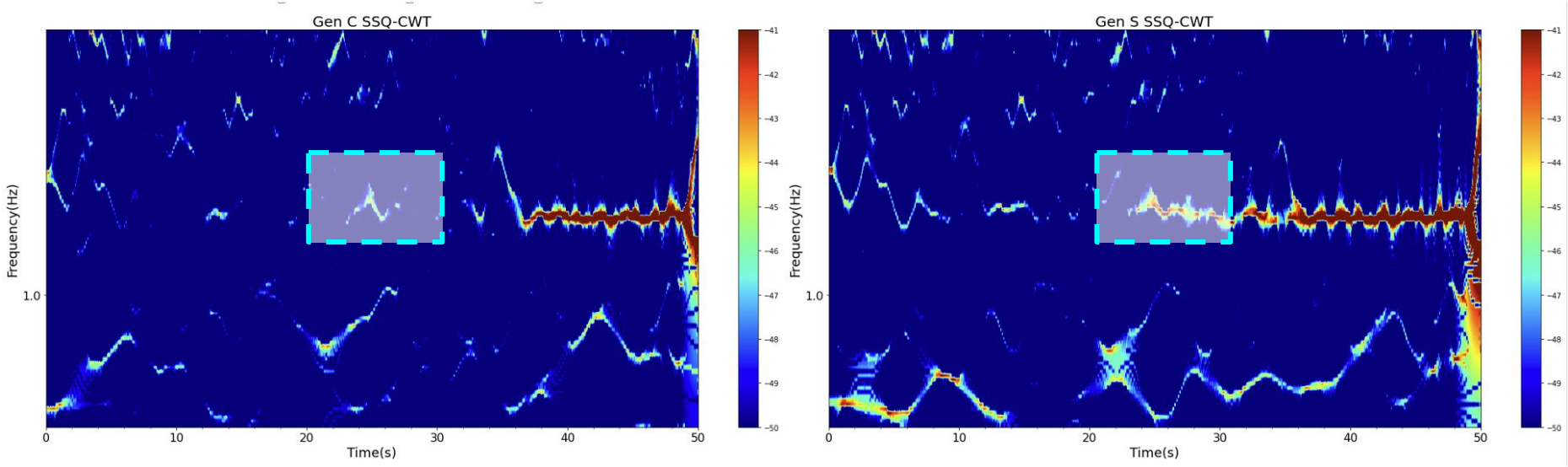
Example 3: Who's Fault Is It?



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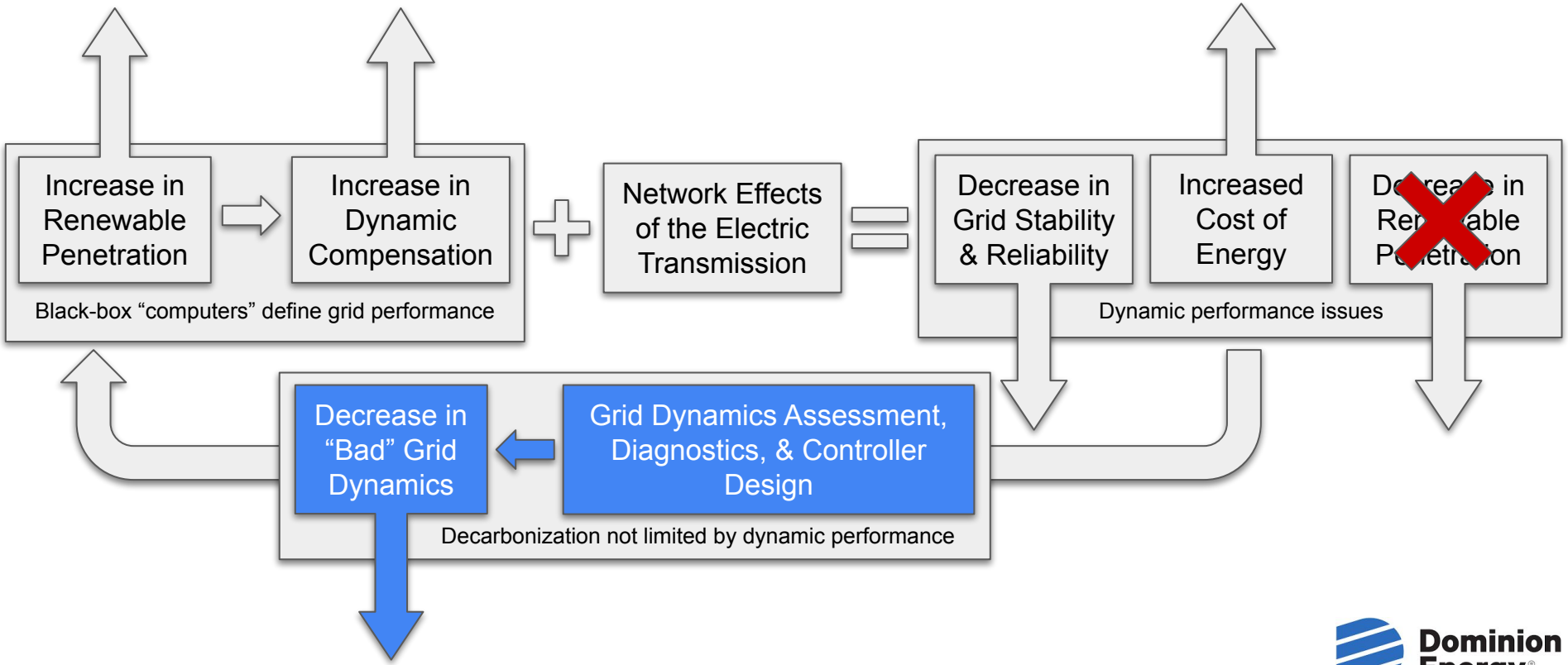
A Necessary Competency for Electric Utilities???



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Our Recent Publications [Jan 2021-Present]

1. C. Mishra, L. Vanfretti and K. D. Jones, "Synchrophasor Phase Angle Data Unwrapping Using an Unscented Kalman Filter," in IEEE Transactions on Power Systems, vol. 36, no. 5, pp. 4868-4871, Sept. 2021, doi: 10.1109/TPWRS.2021.3089027.
2. Mishra, Chetan & Vanfretti, Luigi & Jones, Kevin. (2021). Power System Frequency Domain Characteristics for Inertia Estimation from Ambient PMU Data. IEEE PESGM 2021.
3. de Castro Fernandes, Marcelo & Mishra, Chetan & Vanfretti, Luigi & Jones, Kevin. (2021). A Novel Method for Despiking Spectra from Synchrophasor Measurements. IEEE PESGM 2021.
4. X.Xu, C. Mishra, C.Wang, L.Vanfretti, K.D.Jones, R.M.Gardner, "Fast Oscillation Detection and Labeling via Coarse Grained Time Series Data for ML Applications", ISGT 2022.
5. C. Mishra, L.Vanfretti, D.Yang, C.Wang, X.Xu, K.D.Jones, R.M.Gardner, "Analysis of STATCOM Oscillations using Ambient Synchrophasor Data in Dominion Energy", ISGT 2022.
6. C. Mishra, L. Vanfretti and K. D. Jones, "Designing Time Derivatives in the Frequency Domain for Ambient PMU Data Applications". IEEE PESGM 2022.
7. Eric Segerstrom, Luigi Vanfretti, Chetan Mishra, Xin Xu, Kevin Jones, R. Matthew Gardner, "Using Spectral Flatness to Detect and Label Power System Oscillations in the Presence of Intermittent Broadband Noise". IEEE PESGM 2022.
8. C.Wang, C. Mishra, L. Vanfretti and K. D. Jones, "Identifying Oscillations Injected by Inverter-Based Solar Energy Sources". IEEE PESGM 2022.

Submitted, Under Review

1. de Castro Fernandes, Marcelo; Mishra, Chetan; Vanfretti, Luigi; Xu, Xin & Jones, Kevin. "Experiences with Dynamical Mode Decomposition for Wide-Area Mode Estimation". MSCPES 2022 (10th Workshop on Modeling and Simulation of Cyber-Physical Energy Systems)
2. X.Xu, C. Mishra, C.Wang, , K.D.Jones, L.Vanfretti, "Tracking Periodic Voltage Sags via Synchrophasor Data in a Geographically Bounded Service Territory", IEEE PESGM 2022.

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> 10 years!!

- Distribution is 10x as dense as Transmission…
- Dominion is leading the industry!
- Limited time to reach decarbonization goals (*while keeping the lights on!*)....

< 10 years?!?!

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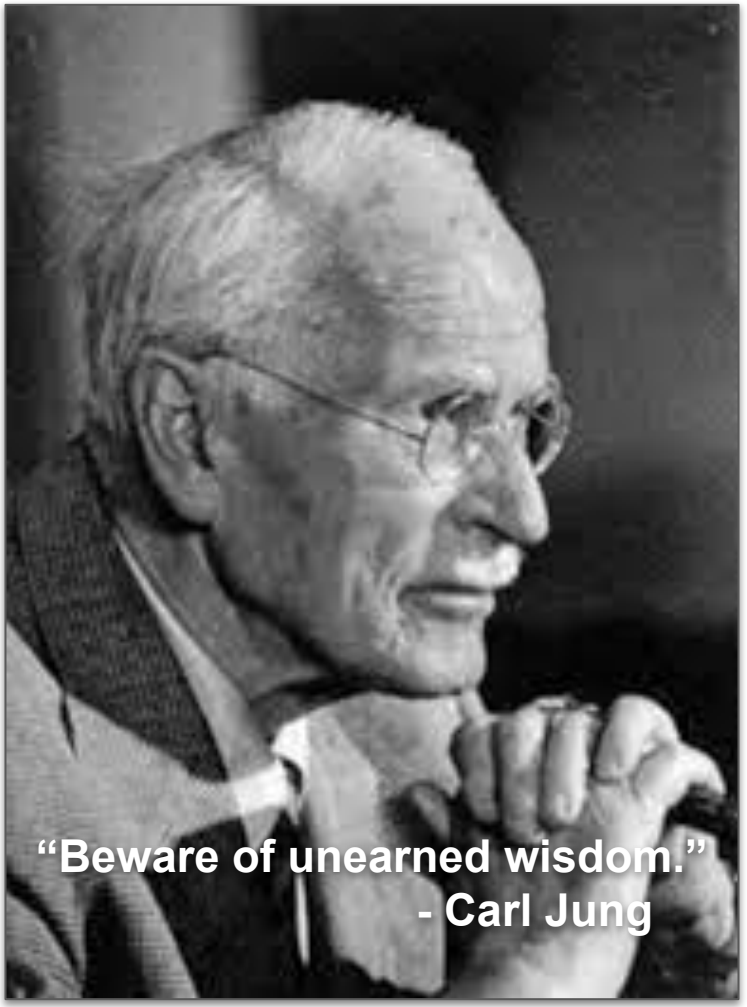
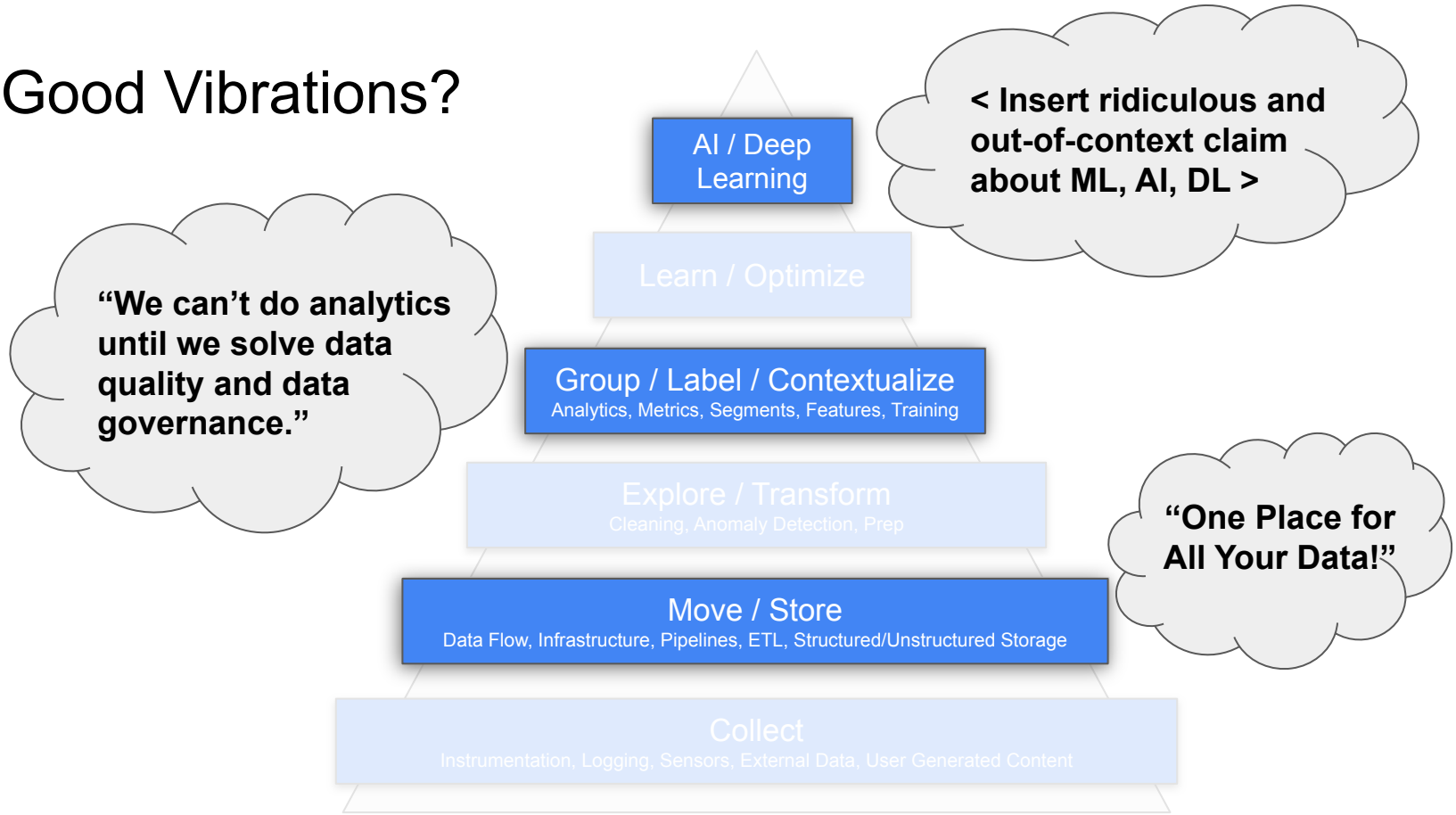
Part 2:
Unearned Wisdom

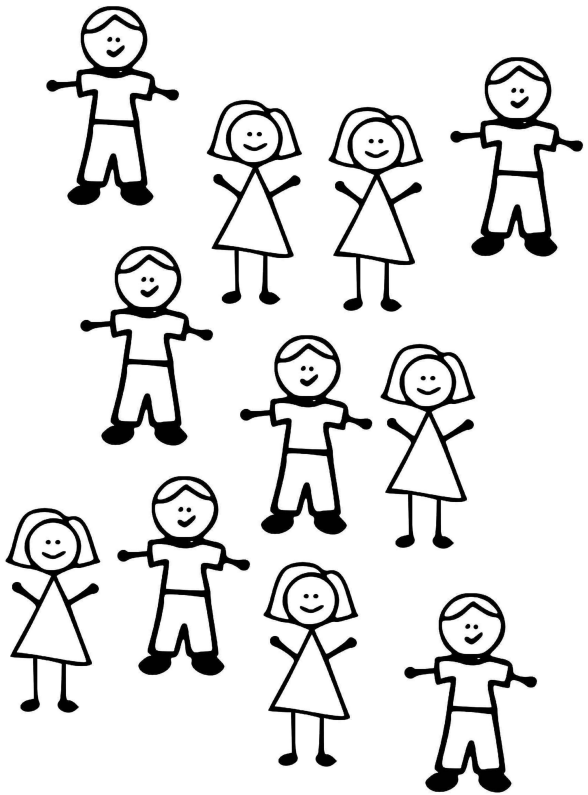
Three data wisdoms
and their corruptibility

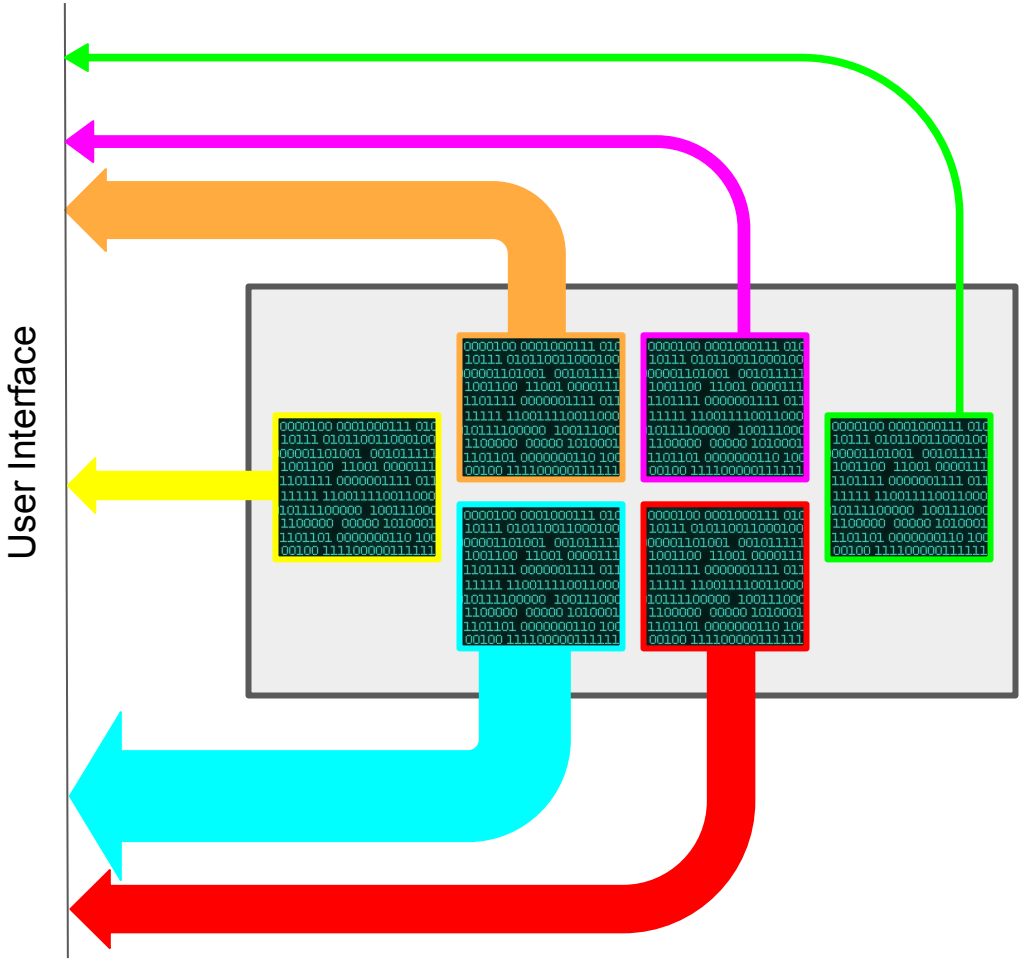


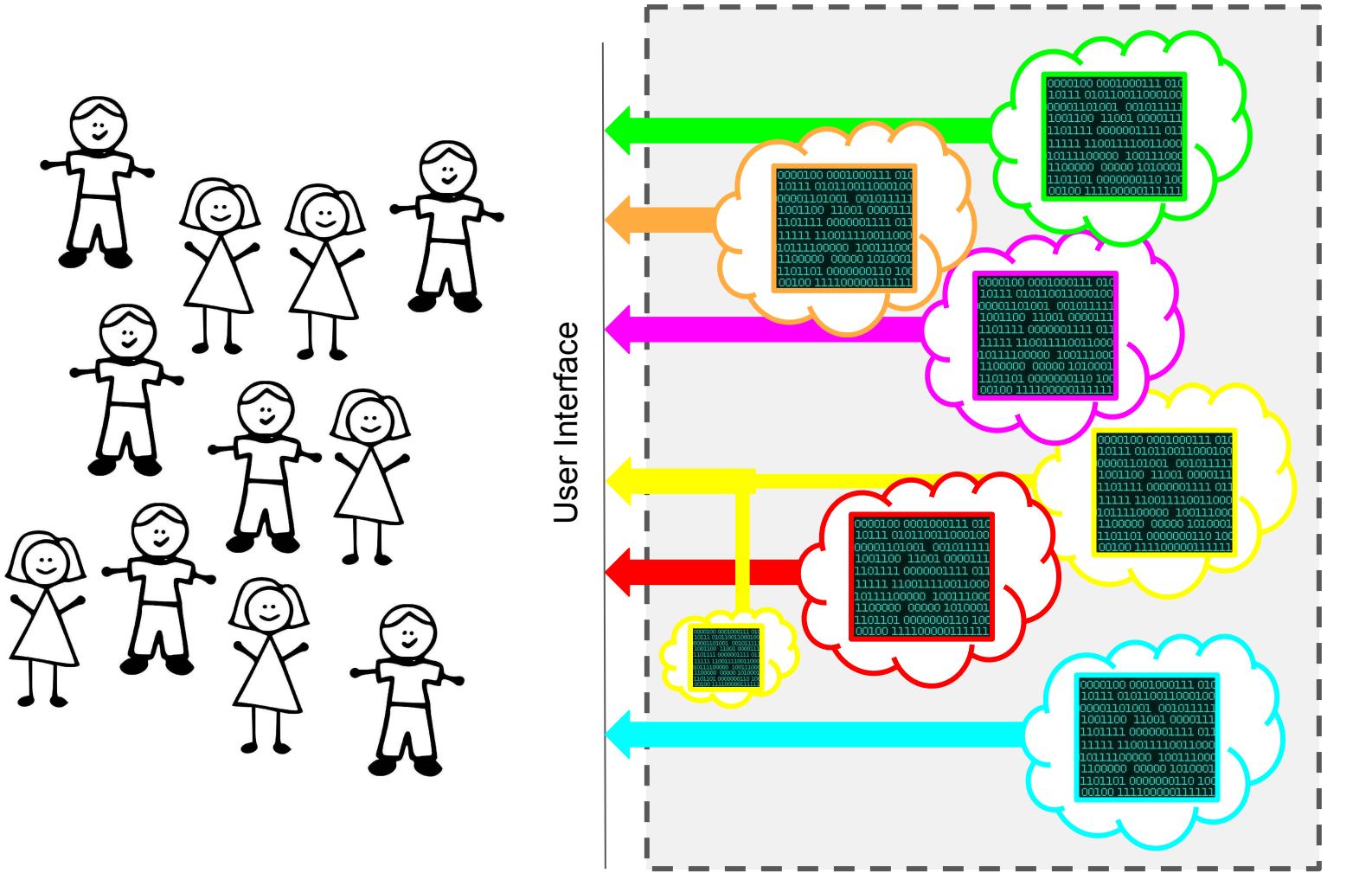
Good Vibrations?



Physical limitation of diverse data modalities yields variable per-unit storage/access costs!!!!!






User Interface

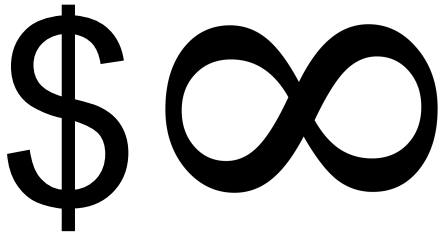
The Cost of Data Quality and Data Governance

~~"We can't utilize data analytics until we *solve* data quality and data governance!"~~

→ How clean & neat does your data need to be?
→ And, how much of your data needs to be *that* clean and neat?

Only as much as is needed for the task at hand.

- **Discoverability** of use cases / applications.
- **Discoverability** of data quality requirements.



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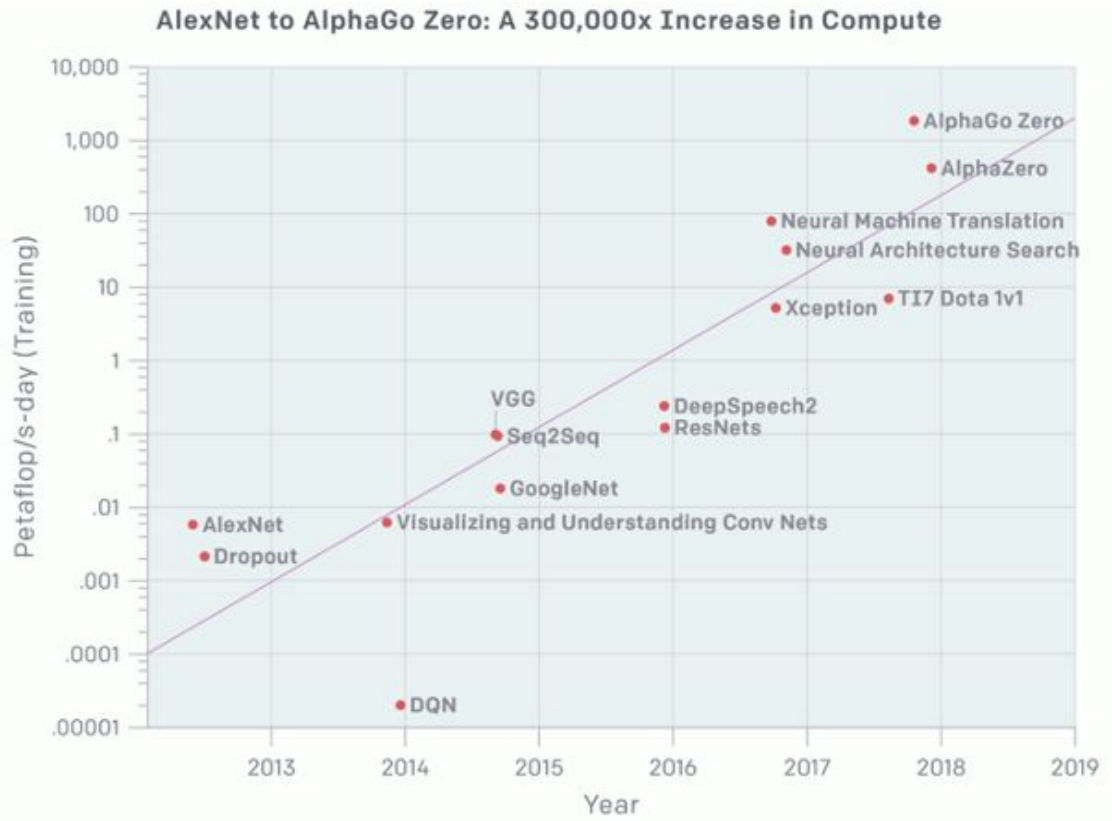
Is AI Eating the World? The Means or the Ends?



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Part 3:
A Better Way?

A Data “Activation Threshold”?

More *sensors*??
More *historical data*??
More *data quality*??
More *compute power*??
More *use cases*??
More *success stories*??
More *ROI*??

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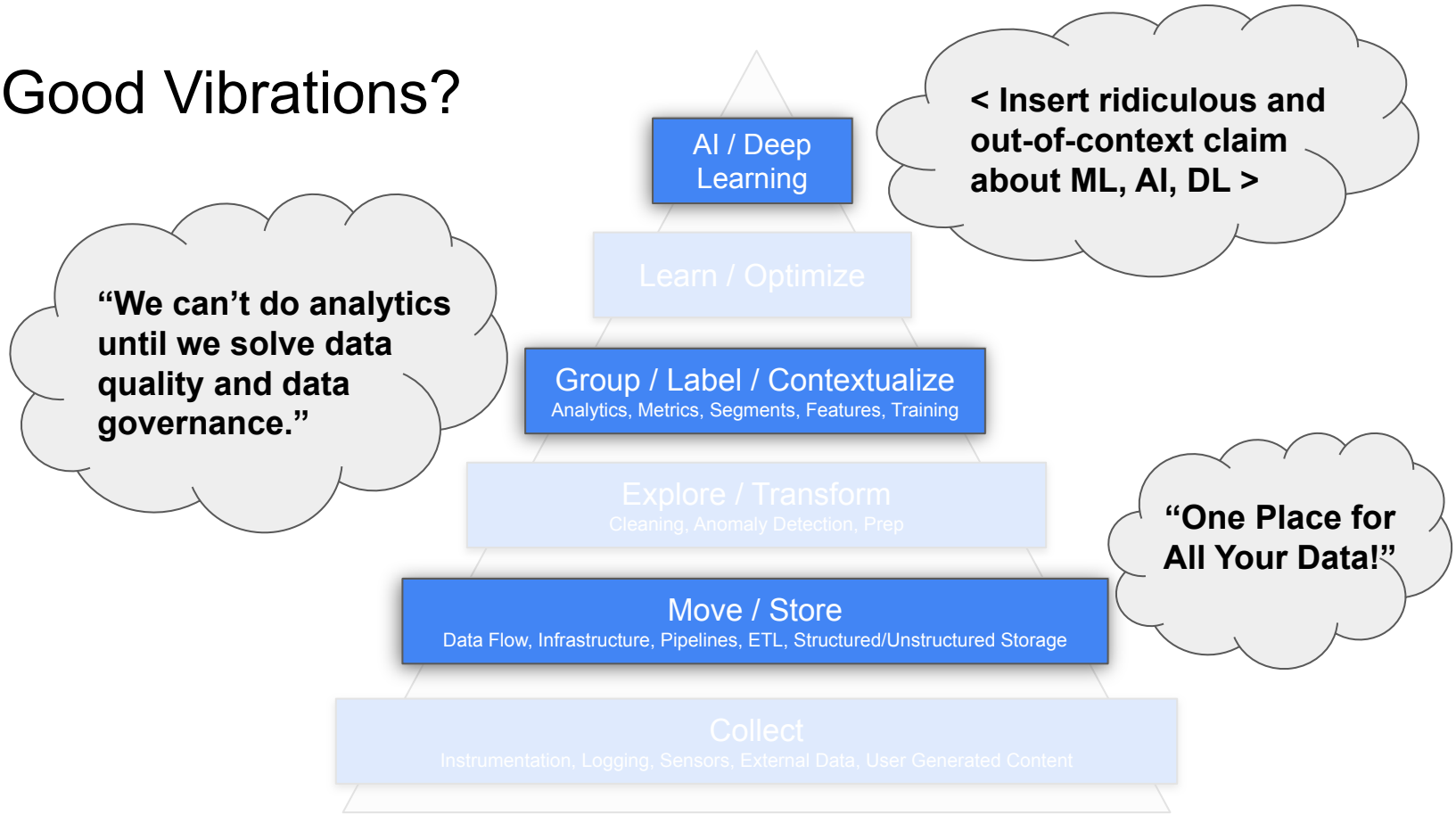
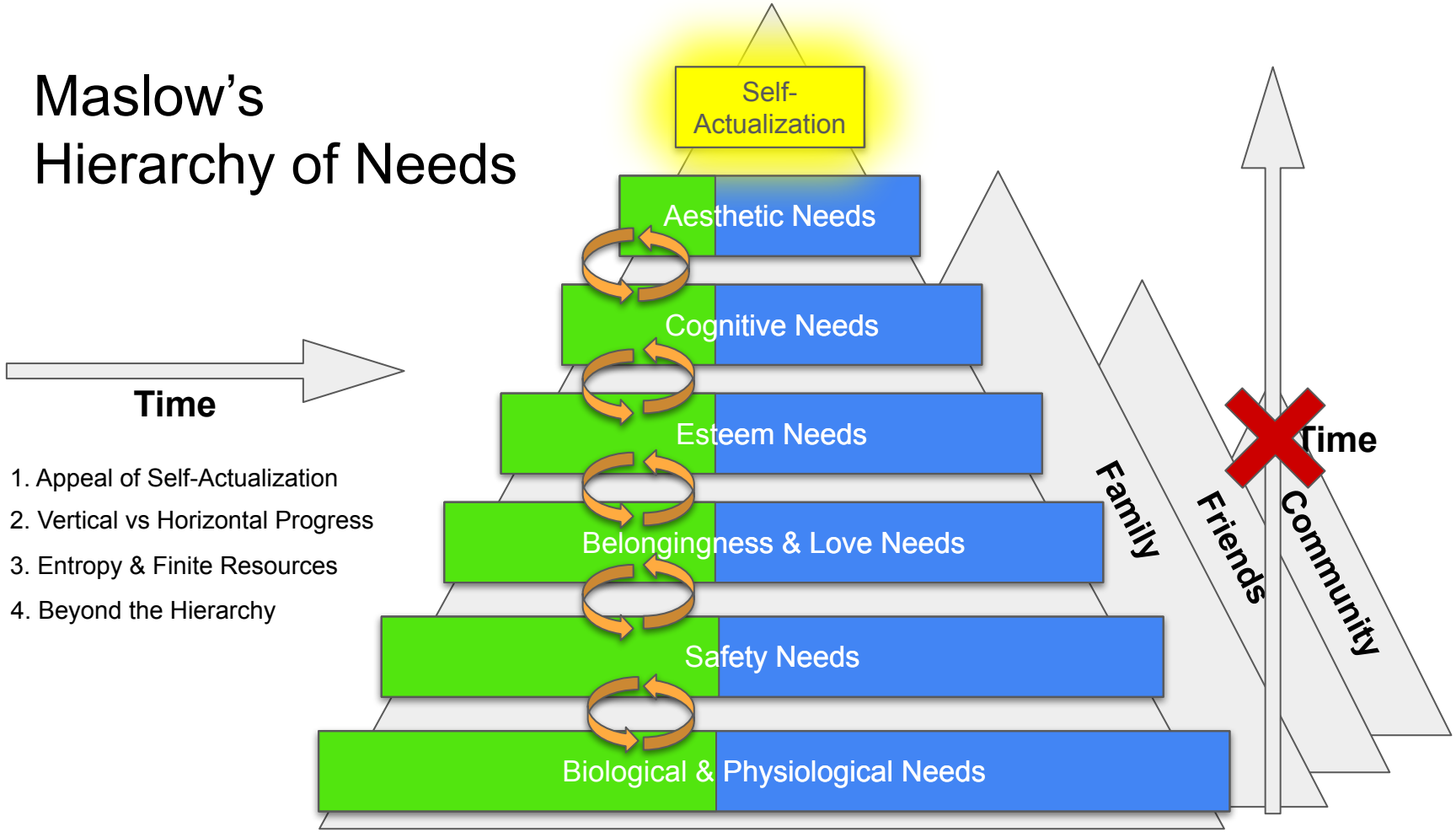
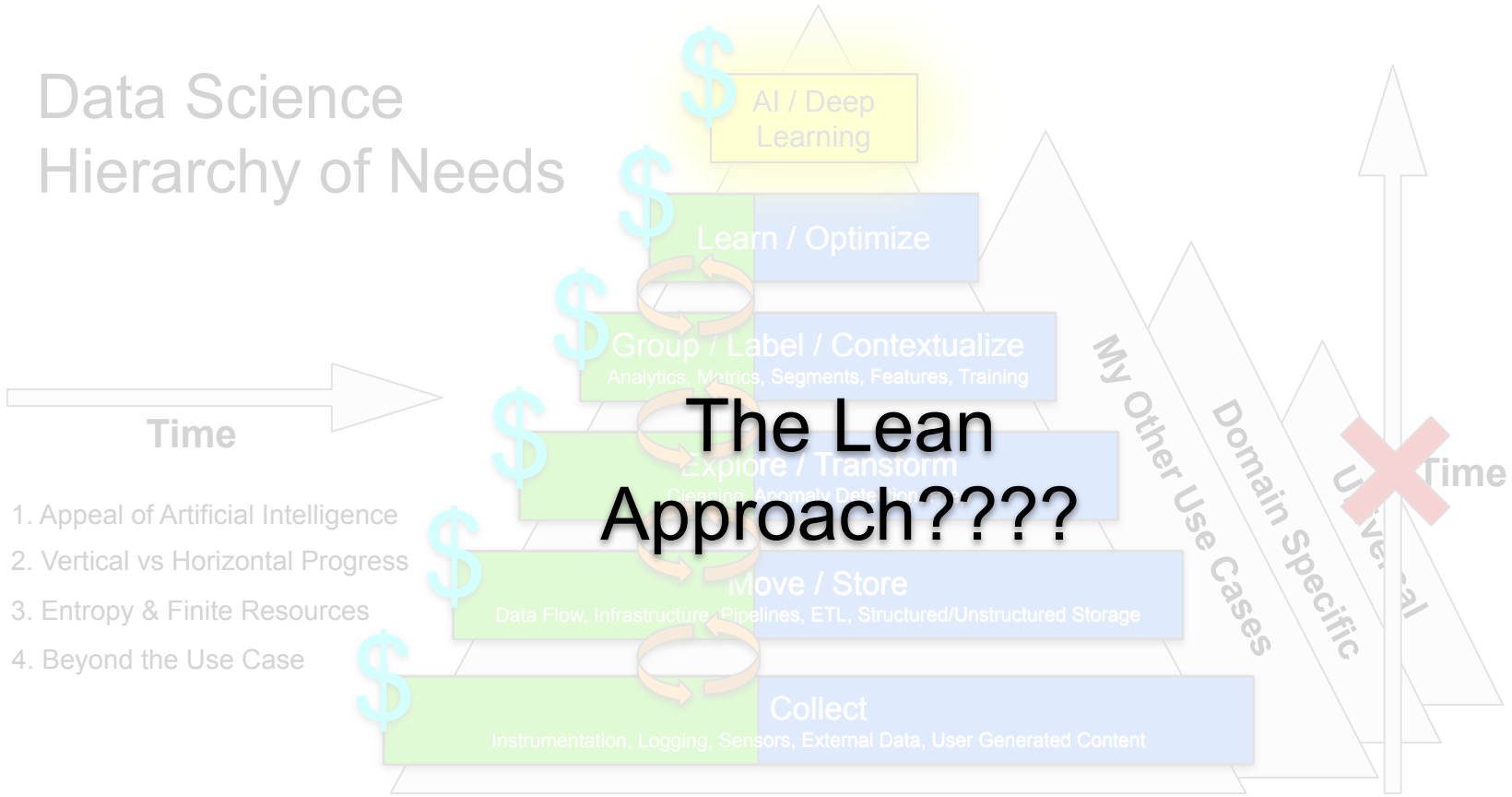
Good Vibrations?



Maslow's Hierarchy of Needs



Data Science Hierarchy of Needs



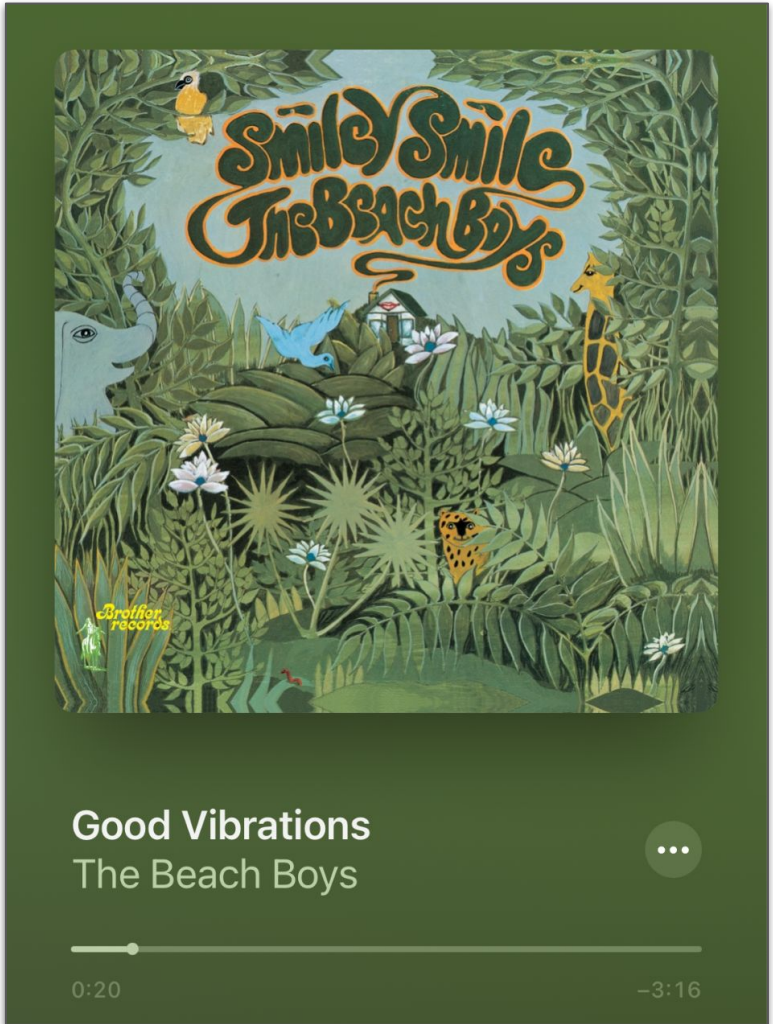
1. Appeal of Artificial Intelligence
2. Vertical vs Horizontal Progress
3. Entropy & Finite Resources
4. Beyond the Use Case

The Lean Approach????

$$f_{cost} = f_{collect} + f_{store} + f_{explore} + f_{label} + f_{learn} + f_{ai}$$

Bonus Track!

Why does any of this matter?



No More Low-Hanging Fruit

Low-hanging fruit: business that are (1) simpler, (2) fundamentally digital in nature, and/or (3) at low risk from change.

- The companies left to digitize haven't earned data wisdom.
- Change happens in two ways: producing *and* consuming
- Company may not have *a priori* knowledge of use cases
- There is likely *something* meaningful at stake
- Practitioners are 1st degree purveyors of wisdom

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Today we learned….

…why electric grid “vibrations” will hold us back and what to do about it.

… how corruptibility of unearned data wisdom can undermine desired outcomes.

… how it is helpful to leverage a holistic cost function for growing the use of data.

… how the alternative approach interestingly reduces to a lean methodology.

… why the remaining digital transformations are so important to get right.

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