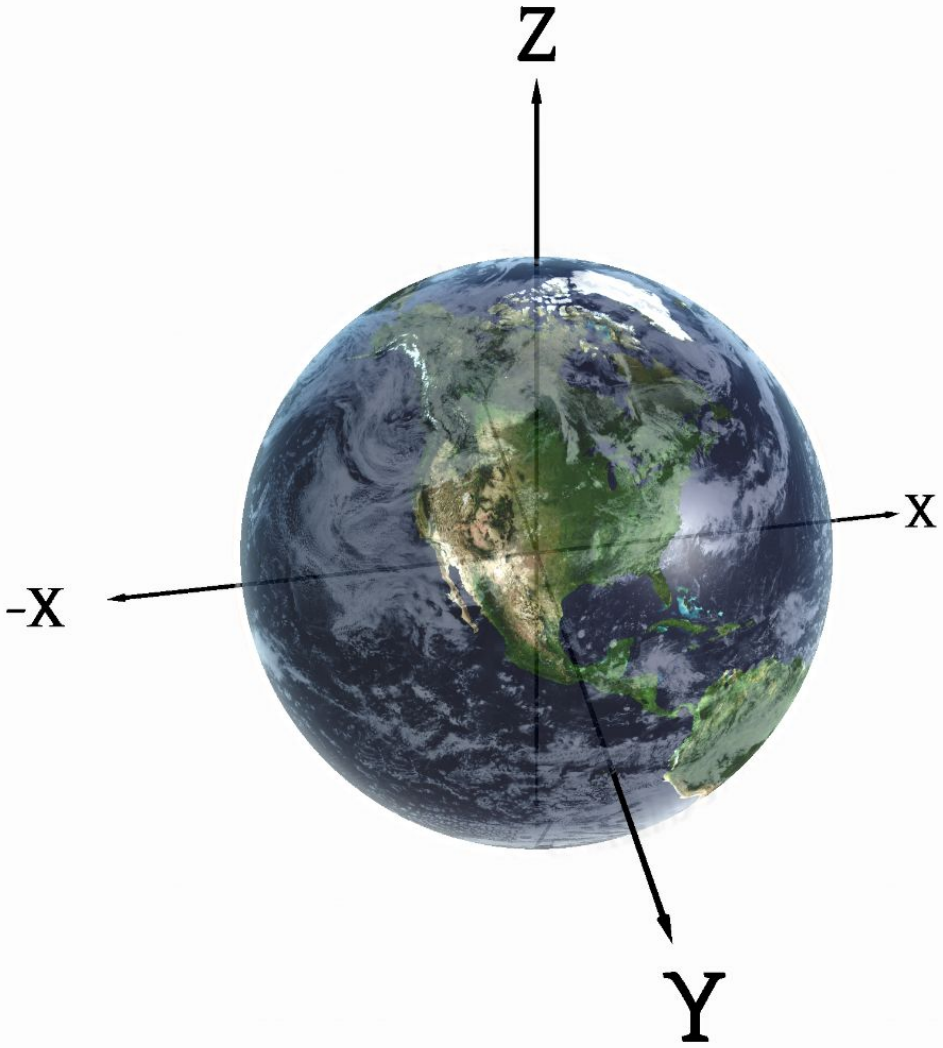
NSF I-GUIDE
DeepEarth Workshop

9th Hour of 168th Day of Year 2025
(41.889306°, -87.619333°, 184m)



LANCE LEGEL
CEO of Ecodash.ai

ecodash

Welcome!

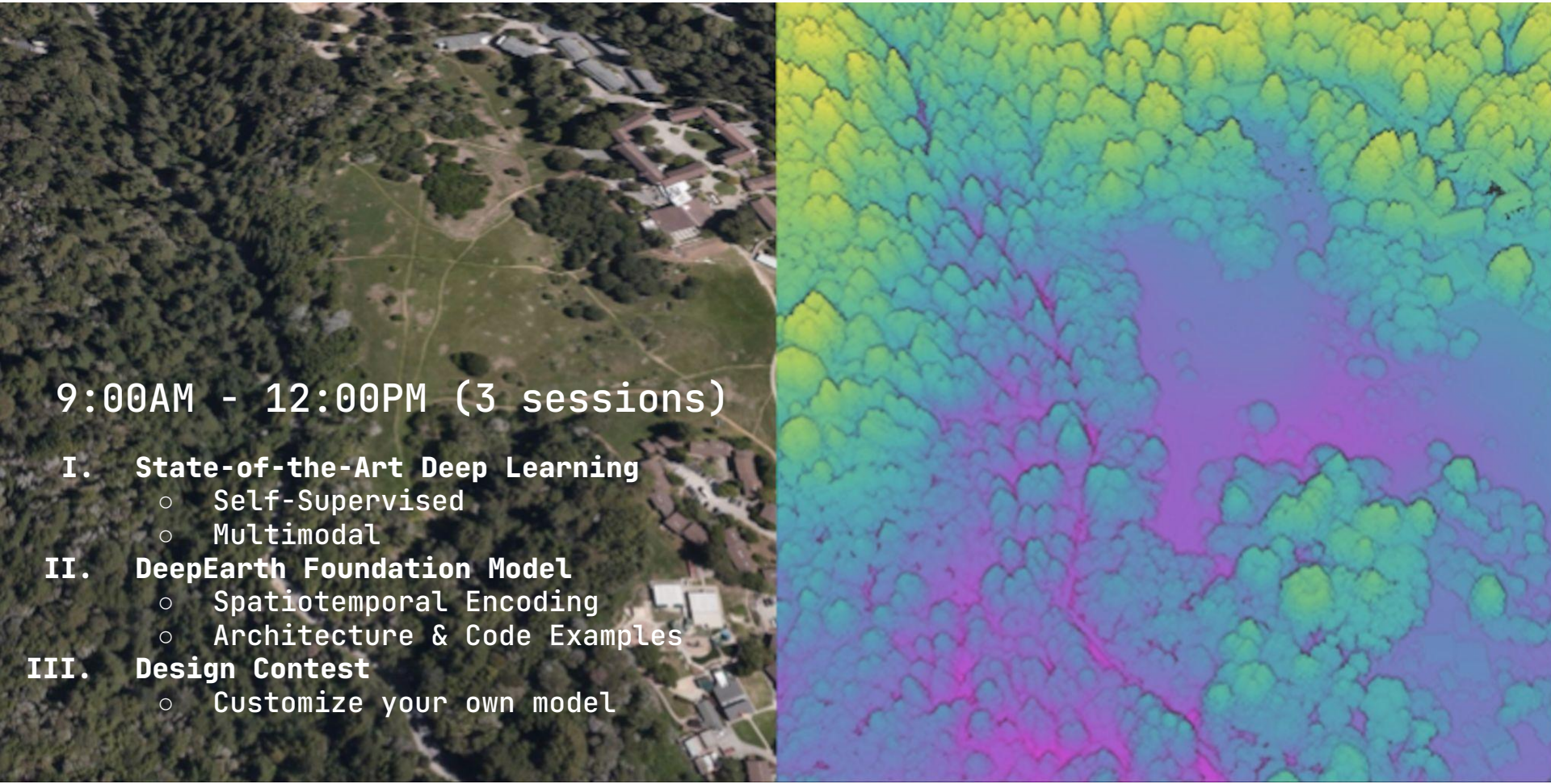
Let's introduce ourselves and get organized...

Archilochus colubris

Art by Petra Stanković

Record of Workshop Participants

- Professor Shaowen Wang, University of Illinois Urbana-Champaign >> NSF I-GUIDE Director
- Professor Danielle Wood, Notre Dame University >> Global Adaptation Initiative
- Professor Fangzheng Lyu, Virginia Tech University >> Geospatial Data Science
- Dr. Wen Zhou, University of Illinois Urbana-Champaign >> GeoAI & Multimodal Simulation
- Dr. Wei Hu, University of Illinois Urbana-Champaign >> Geospatial LLMs & Agents
- Dr. Elham Jebalbarezi Sarbijan, Purdue University, Rosen Center for Advanced Computing
- Dr. Jungha Woo, Purdue University, Rosen Center for Advanced Computing
- Dr. Xin Gu, Texas State University >> Geospatial Urban AI
- PhD candidate Yen-Yi Wu, University of Wyoming, GeoAI + Hydrological and Climate Science
- PhD candidate Nicholas Manning, Michigan State University, GeoAI & Ecology
- MS candidate Ivy Doe Kwashie, University of Wyoming, GeoAI + Digital Twins for Coastal Ghana
- CNA analyst Carey Whitehair-Conde, CNA, GeoAI for Wildfire Threat Detection
- Ecodash.ai CEO, Lance Legel, Ecodash.ai, Director of Ecological Intelligence



9:00AM - 12:00PM (3 sessions)

I. **State-of-the-Art Deep Learning**
   - Self-Supervised
   - Multimodal

II. **DeepEarth Foundation Model**
   - Spatiotemporal Encoding
   - Architecture & Code Examples

III. **Design Contest**
   - Customize your own model

STATE-OF-THE-ART DEMO: **OPENAI** O3 PRO

What is happening?

Request for o3 pro
Reasoned for 2m 47s

The photo captures a brief but telling ecological interaction:

Scene description

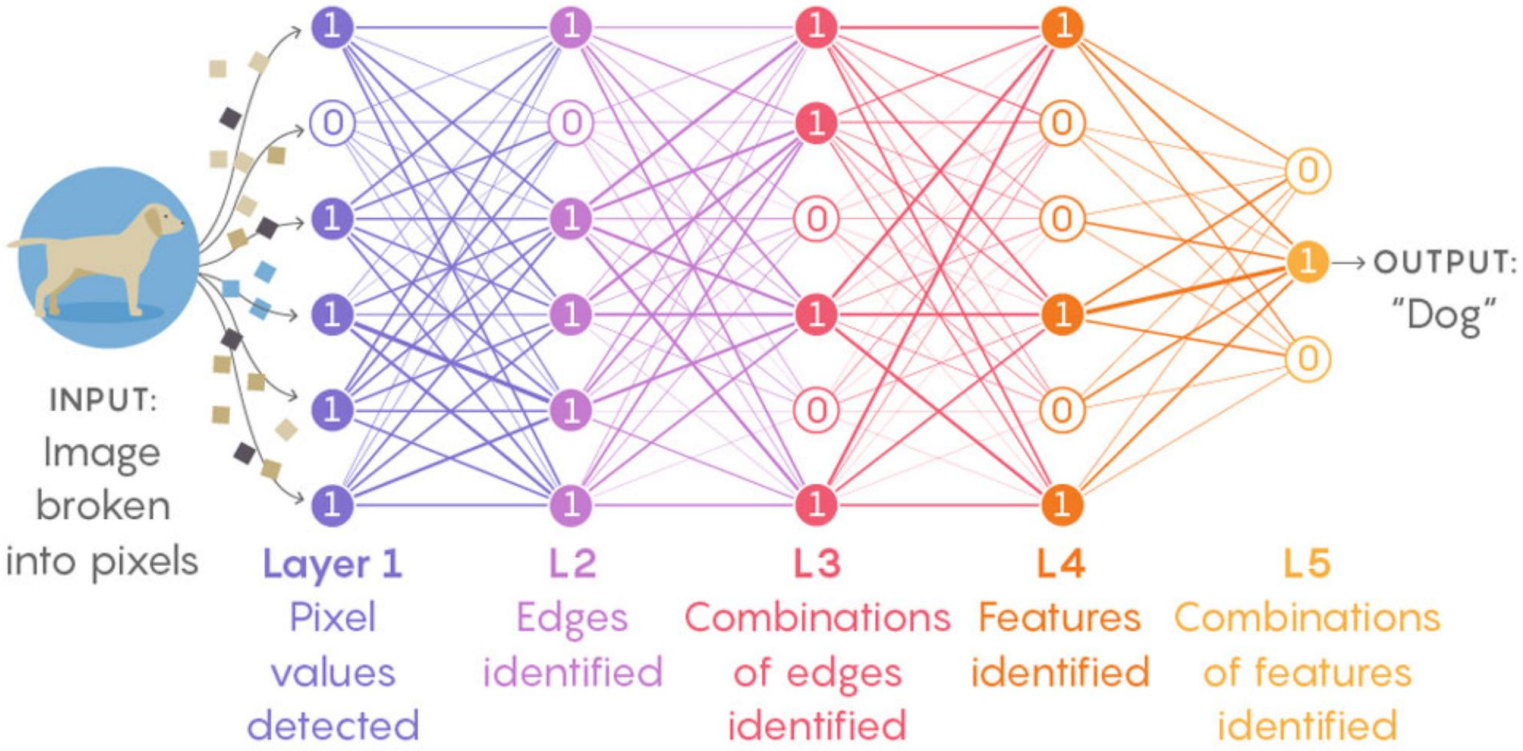
- A hummingbird is hovering nearly upright, suspending itself in the air by rapid wingbeats while probing a tubular, orange-yellow flower with its bill.
- The bird's head and throat flash an iridescent magenta-rose; the back and flanks are metallic green. Those traits, plus the relatively short tail, point to a **male Anna's Hummingbird (Calypte anna)**, a common resident along the Pacific coast of North America.
- The flowers appear to belong to a shrub with paired, trumpet-shaped corollas—possibly a Tecoma or distant relative—whose morphology is well-matched to hummingbird pollination (deep tube, bright warm colors, nectar reward, little scent).

What is happening

1. **Nectar for energy** – The hummingbird is inserting its long, specialized tongue through the corolla to lap up nectar, a high-sugar fuel that powers its extremely costly hovering flight (heart rates >1,200 bpm and wingbeats ~50 Hz).
2. **Pollination service** – As the bird feeds, its forehead and throat contact the flower's reproductive parts. Pollen grains dust the iridescent feathers and will be transferred to the next blossom it visits, completing cross-pollination. This is a classic bird-flower mutualism.
3. **Energetic micro-territorial foraging** – Male Anna's often defend small feeding territories around nectar-rich plants. The vertical perch-and-hover posture and alert eye suggest the bird may dart off momentarily to chase rivals or return to a nearby perch.

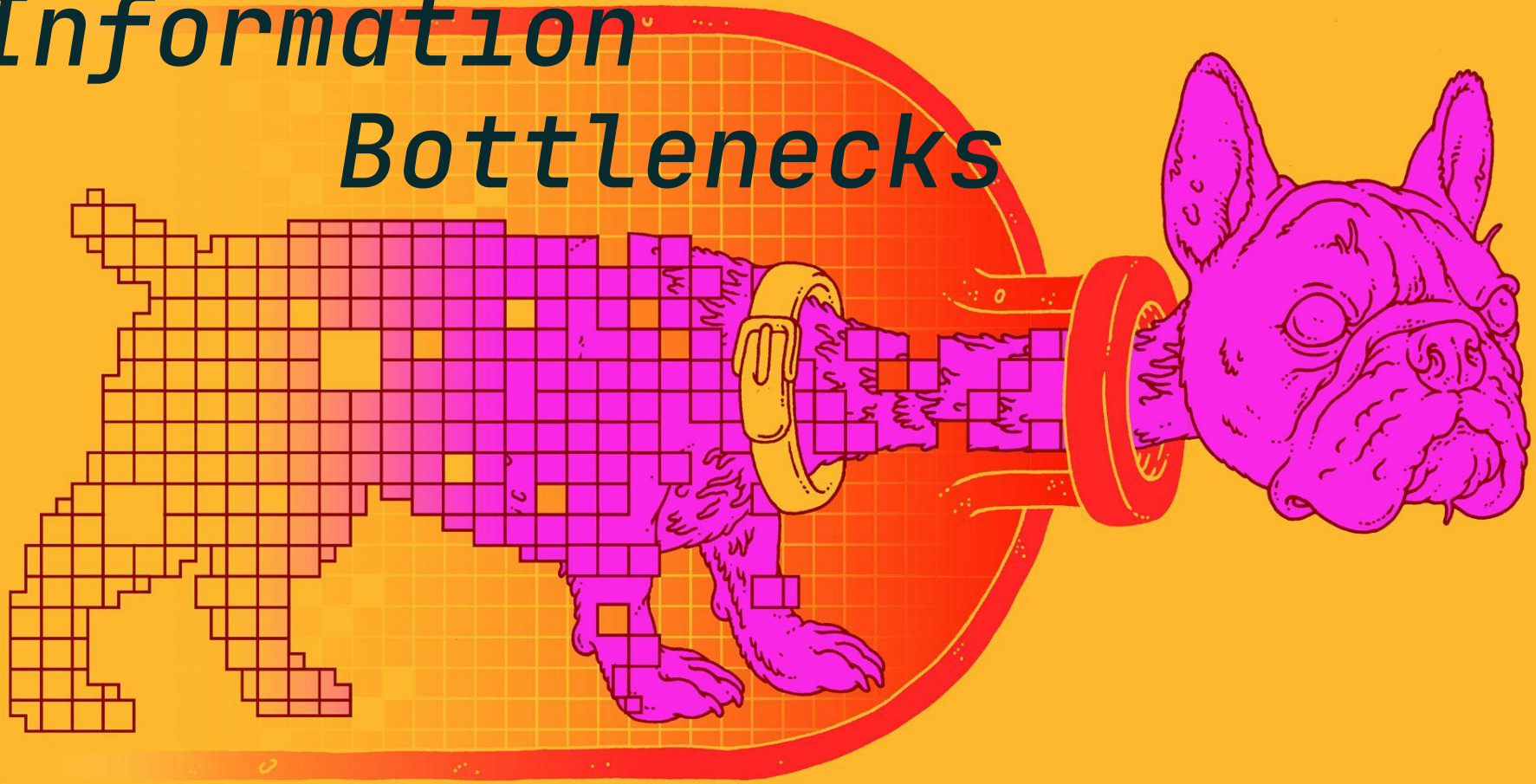
How did we get here?

"In the beginning of deep learning, we had ConvNets"…



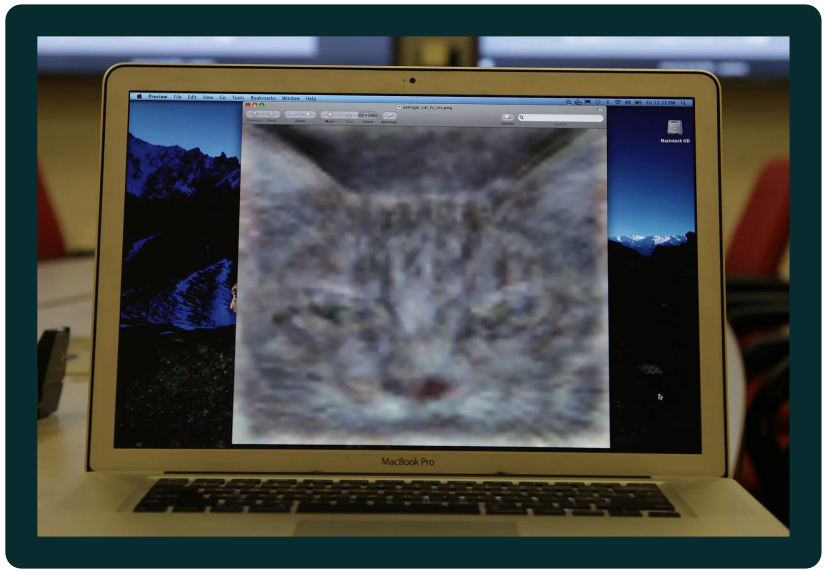
Quanta Magazine, 2017, "New Theory Cracks Open the Black Box of Deep Learning"

Information Bottlenecks

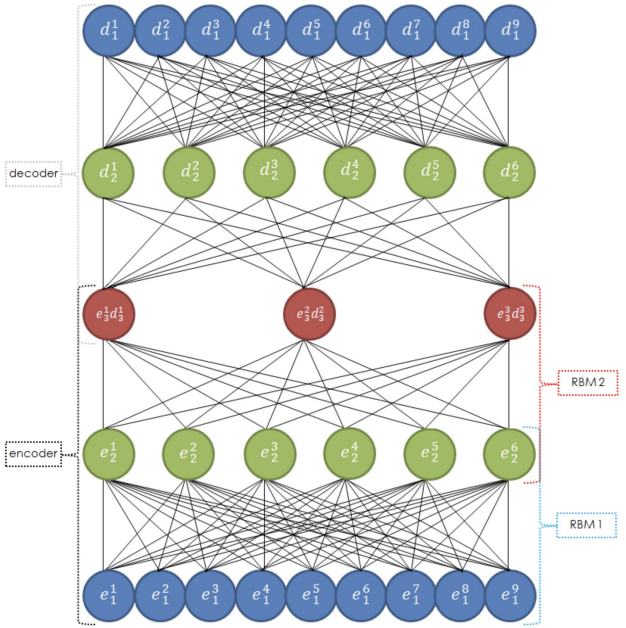


Quanta Magazine, 2017, "New Theory Cracks Open the Black Box of Deep Learning"

Self-Supervised Learning

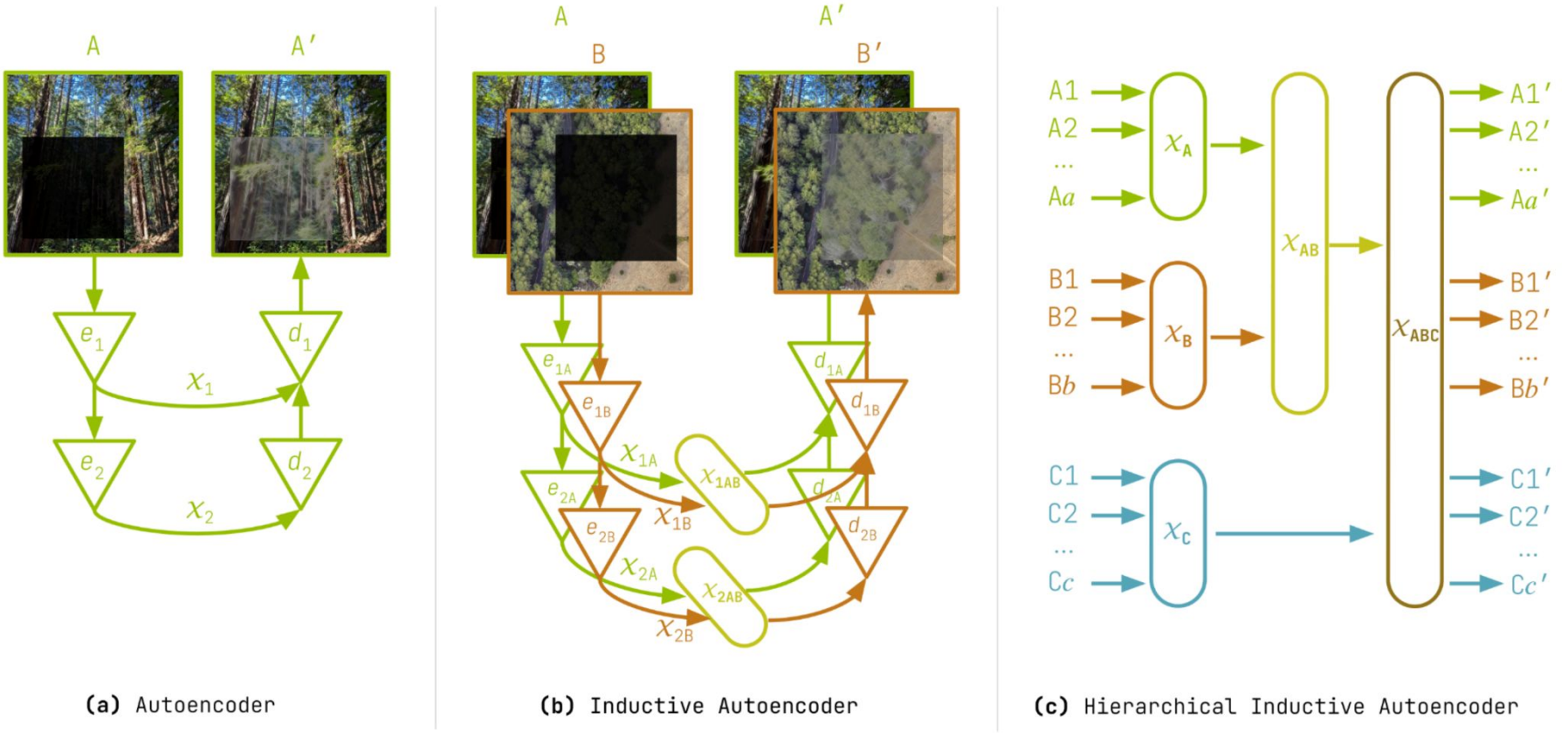


New York Times, 2012,
"How Many Computers to Identify a Cat? 16,000"



Lance Legel, Master of Science Thesis, 2013,
"Parallelized Deep Neural Networks for Distributed Intelligent Systems"

Multimodal Deep Learning



Lance Legel, 2025, "Inductive Neural Networks for Ecology"

Break!

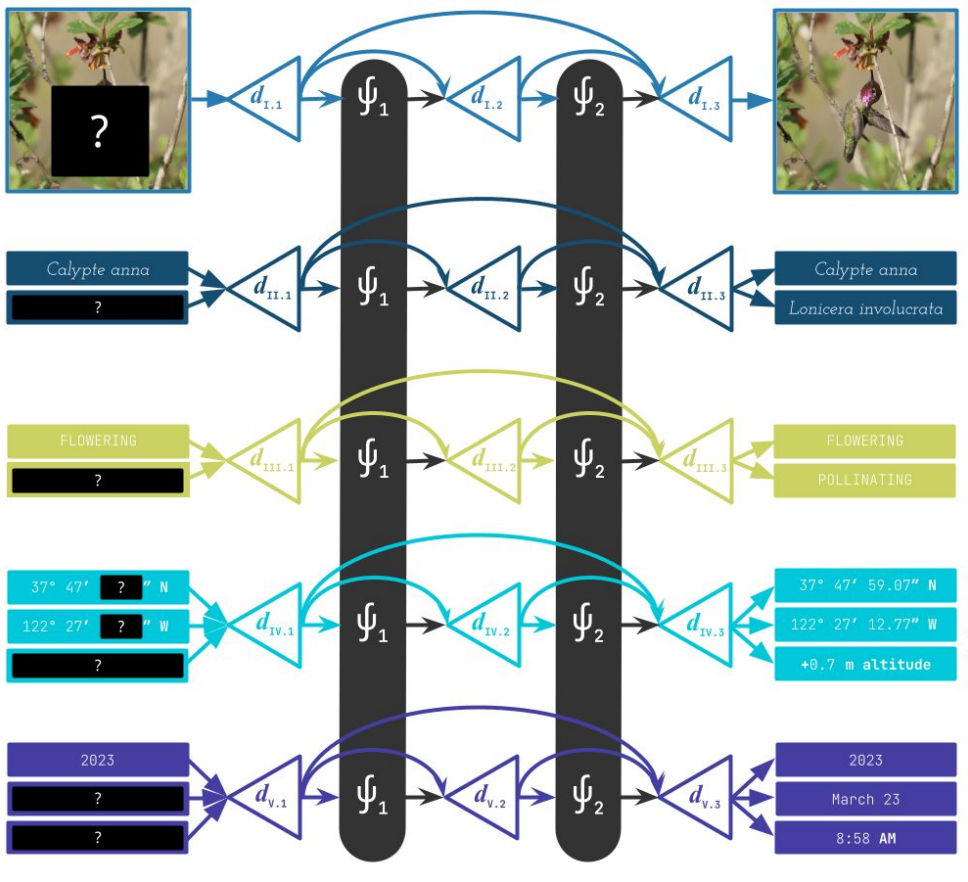
Let's decompress and relax for 5 minutes...

Selasphorus rufus

Art by Petra Stanković

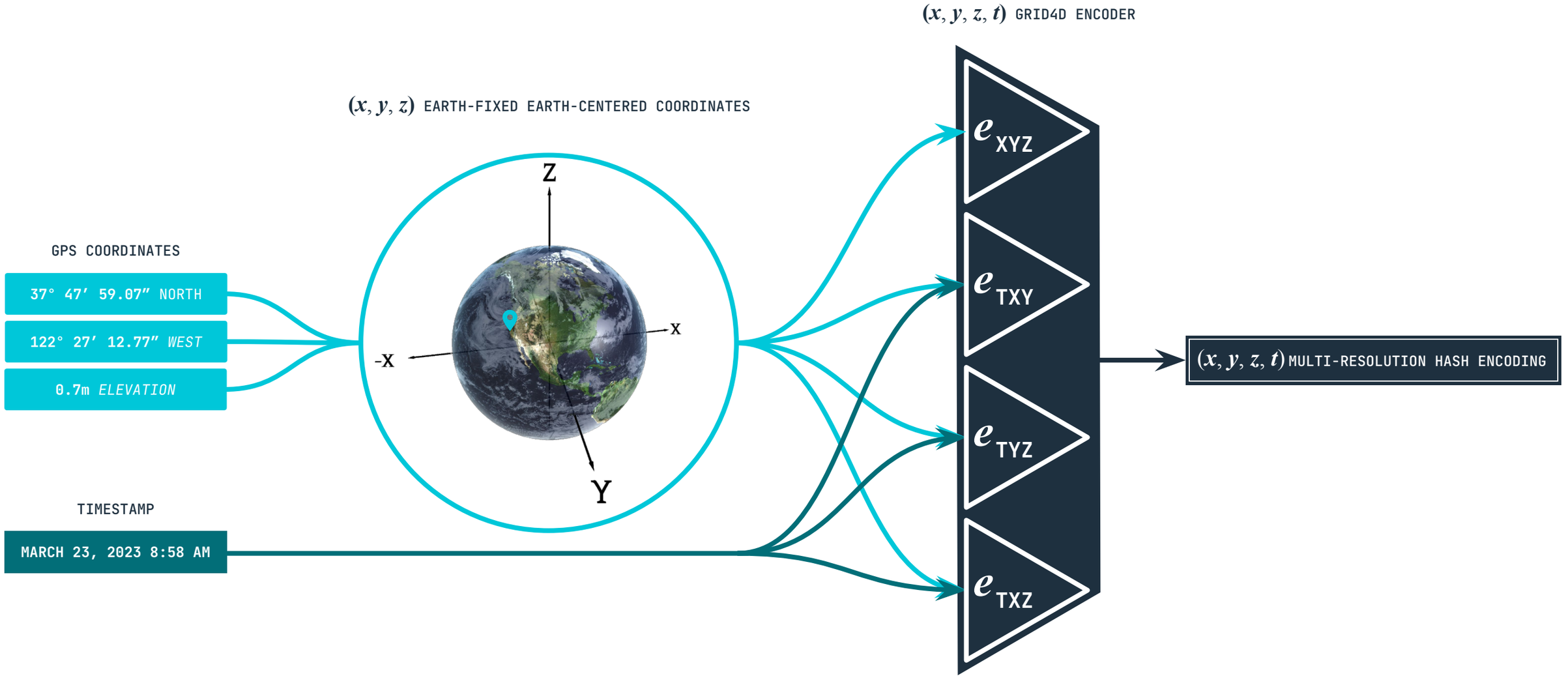
Spatiotemporal Self-Supervised Multimodality Simulator

DeepEarth



Lance Legel, 2025, DeepEarth, https://github.com/legel/deepearth

DEEPEARTH SPACETIME ENCODER



DEEPEARTH INDUCTIVE SIMULATOR

MASKED DATA | MODALITY ENCODERS | DATASET DECODER | SPACETIME EMBEDDING | MULTIMODAL FUSION | INDUCTIVE DECODER | INDUCTIVE SIMULATOR | SIMULATED DATA

DATASET I

DATASET II

DATASET III

DATASET IV

$\mathbb{R}^{I}$ $\mathbb{R}^{II}$ $\mathbb{R}^{III}$ $\mathbb{R}^{IV}$

e_{VISION} e_{LLM} e_{XYZT}

$\mathbb{R}^{VISION}$ $\mathbb{R}^{LLM}$ $\mathbb{R}^{XYZT}$

d_{I} d_{II} d_{III} d_{IV} d_{XYZT}

$\mathbb{R}^{UNIV}$

$\oint_{XYZT}$

ROTARY POSITION EMBEDDING

DEEPSEEK CROSS-ATTENTION

$d_{U\text{-}I}$ $d_{U\text{-}II}$ $d_{U\text{-}III}$ $d_{U\text{-}IV}$

$d_{H\text{-}I}$ $d_{H\text{-}II}$ $d_{H\text{-}III}$ $d_{H\text{-}IV}$

Calypte anna
pollinating
?
flowers

Calypte anna
pollinating
Lonicera involucrata
flowers

Questions & Roadmap (Post-Workshop Notes)

I. **Deep Geometric Vector Encoding**
   - v0.01 Spacetime Encoding is “Pointwise” (“Rasterized”), which is known to be both effective but also potentially very inefficient. How can we teach “vectors”, “polygons”, and “ranges” to the NN?

II. **Bayesian Uncertainty Encoding**
   - Following the workshop, there was a discussion about Gaussian Processes and the potential for explicit modeling of uncertainty. What are some elegant ways to inject uncertainty into the model?

III. **Core Infrastructure Prototyping & Testing**
   - As of June 19th, 2025, DeepEarth’s architecture is more or less fully specified, and peer-reviewed. Collaborators are invited to become core DeepEarth model contributors to bring this to life.

IV. **Custom DeepEarth Model Development, Experiments, and Publications**
   - During the workshop, 6 teams presented adaptations of DeepEarth for their research domain. Let’s plan to explore collaborations to potentially bring such projects to life over the next 3-6 months.

Key Follow-Up References

- DeepEarth Specifications Document including Detailed Python Implementation (2025)
- Foundation Model for Ecology including Historical AI Modeling References (2024)
- Inductive Neural Networks for Ecology including Mathematical Insights & NN Diagrams (2025)
- DeepEarth Pre-Print Preview (Subject to Dramatic Change in Coming Months, 2025)
- NVIDIA Multi-Resolution Hash Encoding: Demos & Paper (2022)
- Stanford lecture on Multi-Resolution Hash Encoding (2022)
- Grid4D encoding of (x,y,z) and time via 4 tri-plane Multi-Resolution Hash Encodings (2024)
- V-JEPA 2 spatiotemporal “world” vision foundation model from Meta (Yann LeCun, 2025)
- ClimaX foundation model for Weather and Climate from Microsoft (2023)
- cBottle foundation model for 1km Atmosphere Modeling from NVIDIA (2025)
- How DeepSeek Rewrote the Transformer [MLA]: Detailing 57x Speed-Up in Transformer (2025)
- Deep Autoregressive Networks: “Universal Distribution Approximator” (2014)
- MADE: Masked Autoencoder for Distribution Estimation (2015)

Thank you!

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Grus canadensis

Art by Petra Stanković