

RISC-V for the Planet

Open Source
Microprocessors on
the Internet of Trees

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USP: Universidade de São Paulo

Excellence in Teaching, Research and Social Impact

18.5%

of Brazilian scientific production

110,000 Highly Qualified People

61K

Undergraduate

30K

Graduate

13.2K

Employees

5.2K

Faculty

Programs and Academic Production

333

Undergraduate
Courses

264

Graduate
Programs

17,600

Published Papers
Year

1,473

Awards and
Honors

**12th university that produces the most
research in the world**
(CWTS 2022)

**247 Researchers among the most
influential in the world**

CITI-USP and the Multiuser Center for Advanced IoT Manufacturing

Interdisciplinary research infrastructure for advanced hardware, rapid prototyping, and pilot-scale IoT manufacturing at the University of São Paulo



A multi-user USP platform that integrates project design, advanced manufacturing, laboratory validation, and digital infrastructure for connected hardware systems.

Fabrication & prototyping

InovaLab provides additive and subtractive manufacturing infrastructure, including multiple 3D printers, high-precision CNC machines, and laser cutting systems.

Test & validation

Laboratory instrumentation supports the development and testing of highly integrated electronic circuits, complemented by the LEA audit and testing laboratory.

Digital design backbone

High-speed networking, high-capacity servers, and CAD environments such as Altium, KiCad, Cadence, AutoCAD, and Autodesk Fusion support hardware design and AI optimization.

CITI-USP operates as an academic infrastructure platform that shortens the distance from concept to validated prototype, strengthening interdisciplinary research, training, and institutional innovation capacity.

Our Team



Tropical Vulnerability: The 25.4°C Threshold

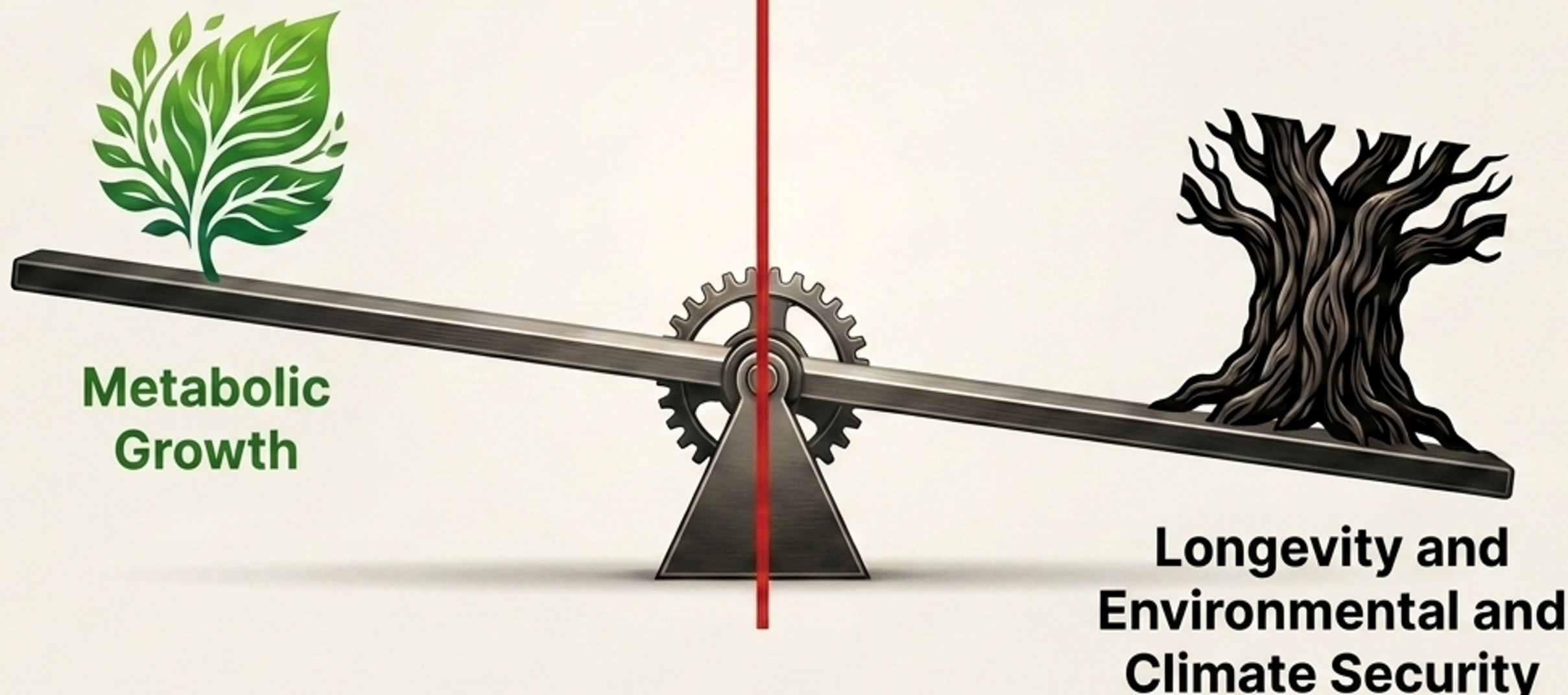
25,4°C

The CO₂ Paradox:

Hot environments induce rapid growth, but severely compromise the mechanical stability of trees.

The Critical Point:

Tree longevity drops drastically. A small fraction of a degree redefines global carbon resilience.



Extreme Climate Events Around the Globe

CLIMATE CATALYSTS

The frequency, intensity, and duration of climate extremes have increased, posing unprecedented challenges to societal stability. These events exert profound impacts on human livelihoods and ecological integrity.

Primary Threats:

- Floods & Storms: Frequent and costly natural disasters affecting millions annually.
- Wildfires: Intensified mega-fires complicating behavior prediction.
- Droughts: Record low water levels causing agricultural and ecological damage.
- Tornadoes: Severe atmospheric mechanisms impacting local communities.



[nature](#) > [editorials](#) > article

EDITORIAL | 10 June 2026

The Amazon can be saved – with concerted action inside and outside Brazil

As deforestation in the Amazon falls, fresh evidence shows that the rainforest can withstand global warming, but only if there is a worldwide effort to stop cutting it down.

The Anthropocene and Our Data Blindness

Macro-Blindness

Persistent Perception

1

The Macro Threat



Climate instability is accelerating beyond predictive satellite models.

2

The Micro Deficit



Orbital tools cannot penetrate dense canopies to retrieve localized ground-truth data.

3

The Solution Paradigm



We must embed persistent perception directly within the biome.

The Observation Bottleneck: The Limits of Traditional Techniques vs. IoT Forest Probes

Method	Coverage	Latency	Energy Cost	Canopy Penetration
Remote Sensing (Satellites/Drones)	Global	High (Days)	High	None (Blocked)
Lab Equipment (GC-MS)	Micro-Local	Hours	Very High	Infeasible in the Field
Traditional IoT	Local	Seconds	High (Batteries die)	Medium
Persistent Micro-Sensing	Distributed	Real-Time	Ultra-Low	Deep (Leaf Level)

The Next Wave: IoT Forest Probes overcome limitations, scaling perception to billions of leaves.

Voyager-1: The 50-Year Miracle of Minimalist Computing

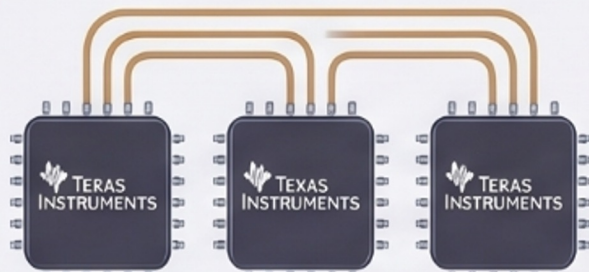
Hardware Specs: Doing More with Less

70 Kilobytes of Total Memory

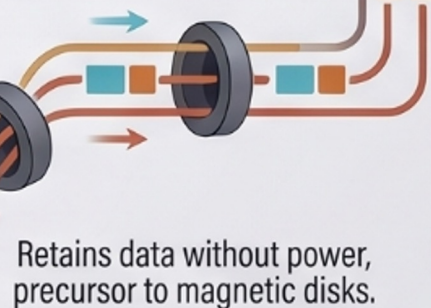


Smaller than one smartphone thumbnail, yet captured Jupiter's rings.

Pre-Microprocessor Technology



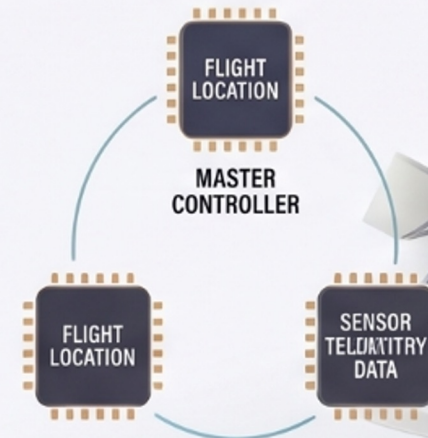
Non-Volatile Magnetic Memory



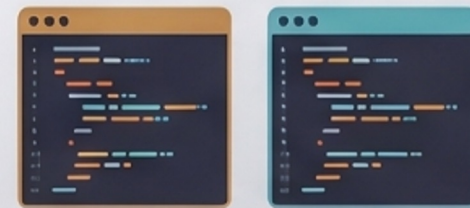
Retains data without power, precursor to magnetic disks.

System Architecture & Redundancy

The Triple-Computer Core



Replicated Code for Survival



Every computer has a dedicated backup to survive failures.

1950s Software Foundation



The Long-Distance Maintenance

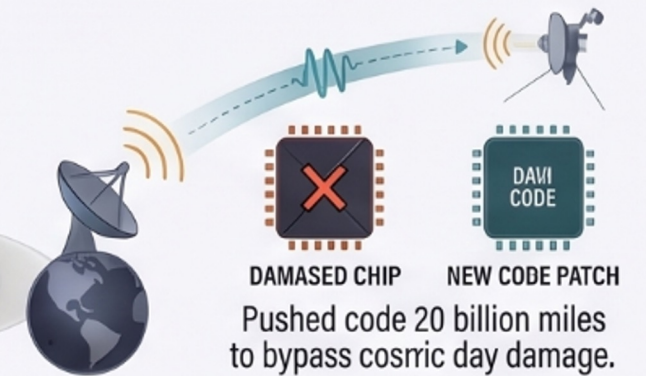
Current Distance:
Over 20 Billion Miles

50 Years of
Non-Stop
Operation

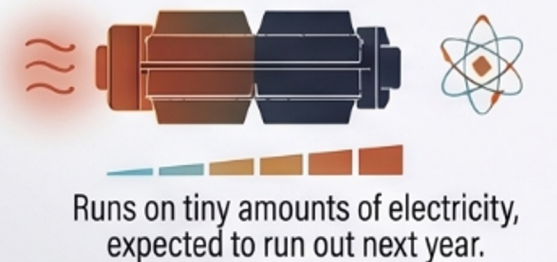


Record for longest continuous
operation of a single system at 10 km/sec.

Remote "BIOS" Update



Plutonium Power Source

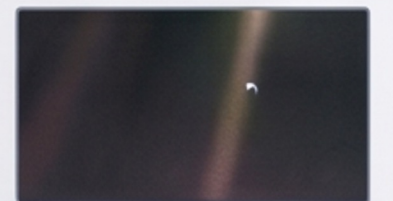


Runs on tiny amounts of electricity,
expected to run out next year.

Legacy and the "Pale Blue Dot"



**Humanity's Interstellar
Ambassador:**
Carries Mozart and Fortify
voices for any alien life.



"Just a Pale Blue Dot"
- Reminding humanity of its
small place in the universe.

TREE LONGEVITY IN THE AMAZON

WHAT THE SCIENCE SAYS

Global tree-ring analysis reveals rapid decrease in tropical tree longevity with temperature.

Maselli et al., PNAS (2020)

HOW LONG DO AMAZON TREES LIVE?

Average longevity in years

208
years

Warm / Wet Tropical Forests
(including the Amazon)



Global Tropical Average
186 ± 138 years



Warm / Dry Tropical Forests
137 years



We are not just placing computers in the forest: we are creating a **symbiotic digital perception system**.



Tropical trees grow about twice as fast, but live significantly shorter than trees outside the tropics (322 ± 201 years).



Longevity is a key determinant of how much carbon forests can store. Shorter-lived trees mean **less carbon stored over time**.

WHAT CONTROLS TREE LONGEVITY IN THE TROPICS?



TEMPERATURE EFFECT

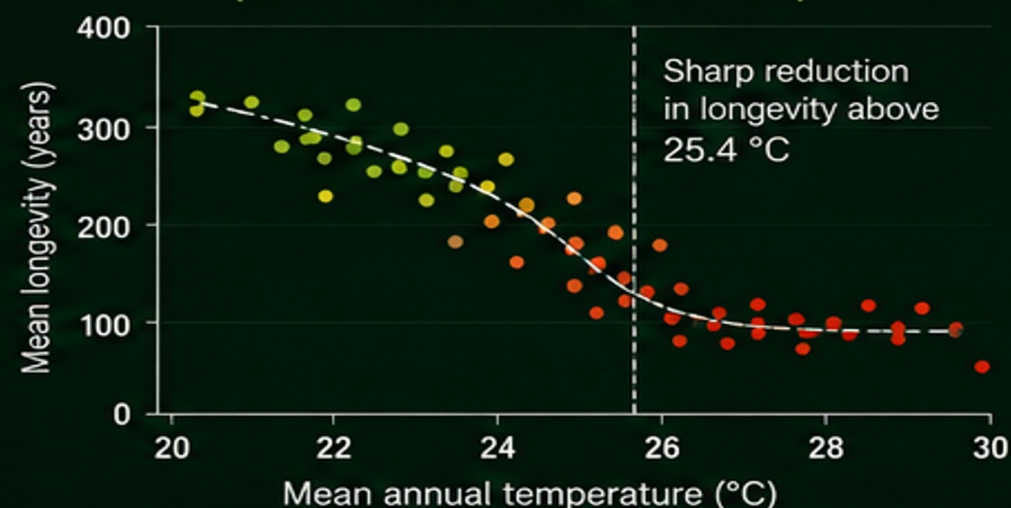
Strong decrease in tree longevity above mean annual temperature of **25.4 °C**



WATER AVAILABILITY EFFECT

Tree longevity consistently decreases with increasing aridity (drier conditions).

TREE LONGEVITY VS. TEMPERATURE (WARM TROPICAL LOWLANDS)



WHY THIS MATTERS FOR THE AMAZON



Warming and drying trends may reduce tree longevity, increasing tree mortality and changing forest composition.



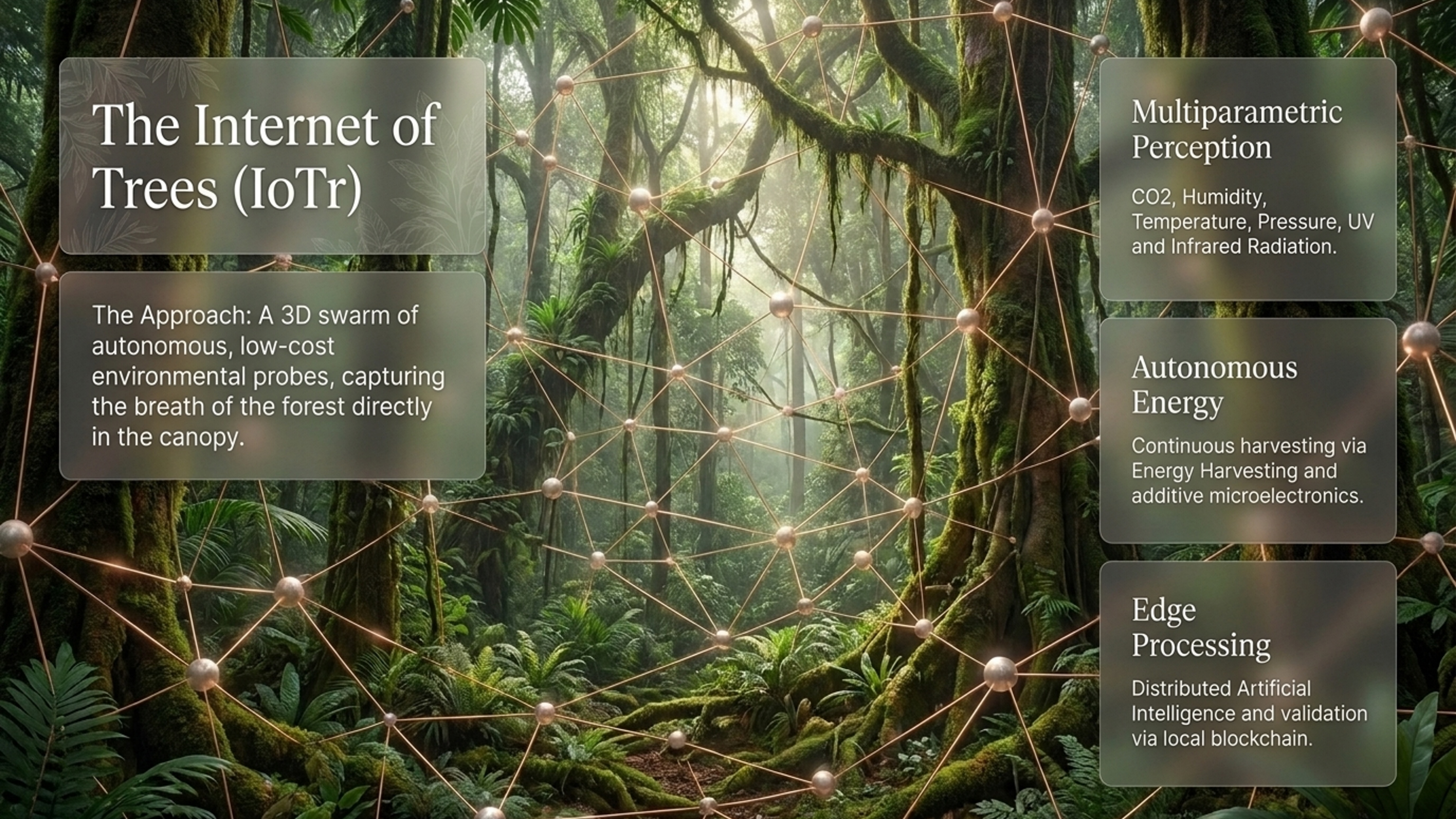
Shorter-lived forests store less carbon over time, amplifying climate change.



Long-living digital probes are essential to continuously monitor, understand and protect our forests for generations.



If forests are to live with the trees, our technology must be open, durable, and designed for decades—just like the forest itself.



The Internet of Trees (IoTr)

The Approach: A 3D swarm of autonomous, low-cost environmental probes, capturing the breath of the forest directly in the canopy.

Multiparametric Perception

CO₂, Humidity, Temperature, Pressure, UV and Infrared Radiation.

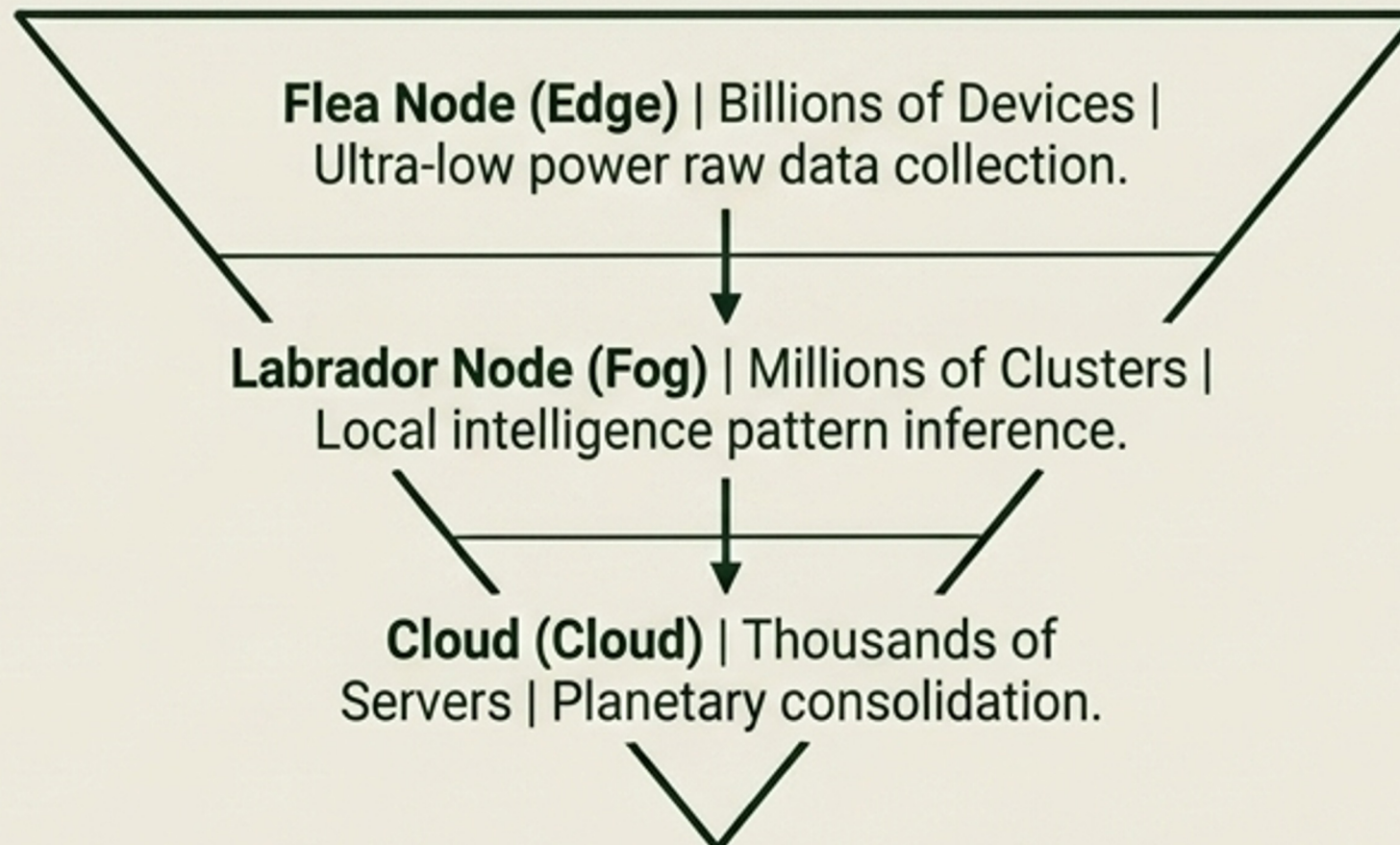
Autonomous Energy

Continuous harvesting via Energy Harvesting and additive microelectronics.

Edge Processing

Distributed Artificial Intelligence and validation via local blockchain.

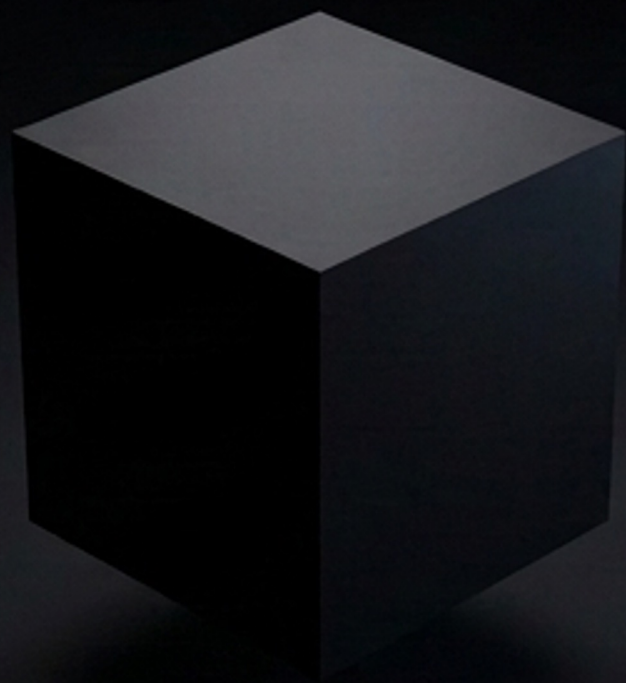
Swarm Intelligence: The Cognitive Edge



Biological Mimicry:

The cloud does not scale for the deep forest. To save battery, processing must occur within the swarm itself.

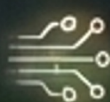
The Choice for Open Silicon: Longevity and Digital Sovereignty



The Black Box

Proprietary Silicon

- Secret instruction sets, reliance on foreign intellectual property, architectural bloat, and zero localized control.



The Glass Box

RISC-V Architecture

- Open-source instruction set, complete design transparency, extreme customizability, and absolute digital sovereignty.
- Open standards expand computer system longevity by enabling continuous community-driven updates, maintenance, and future-proofing, avoiding obsolescence.





**SBCs designed and
manufactured in Brazil**



**Open Hardware
and Software**



**Focus on
AI edge computing**

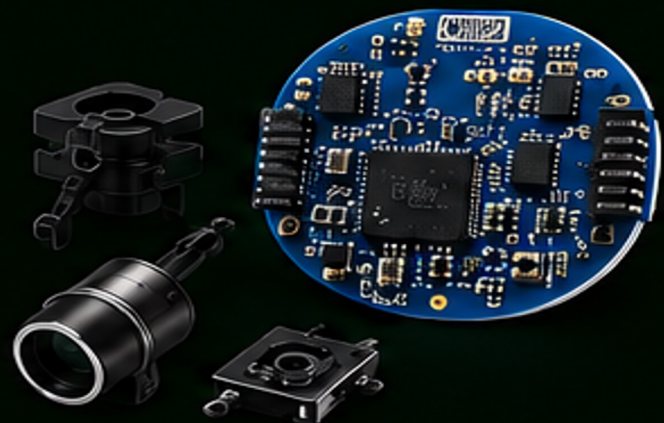


CANINOS LOUCOS FAMILY

Boards and intelligent solutions for innovation without limits.



FLEA



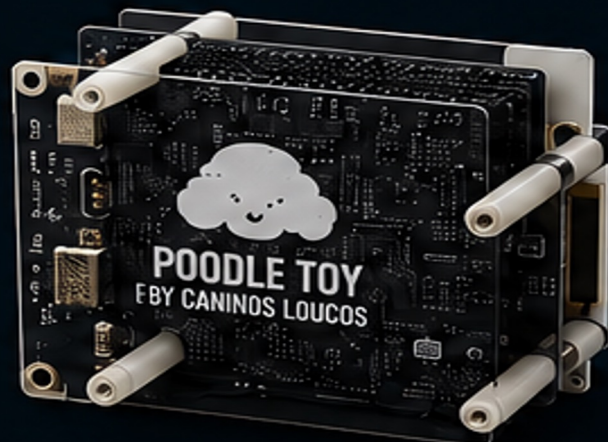
SMALL. SMART. POWERFUL.

- ✓ Small form factor
- ✓ Coin-sized
- ✓ Autonomous
 - Low power
 - Energy harvesting
- ✓ Wireless communication
- ✓ Cryptography support

IDEAL FOR



POODLE TOY



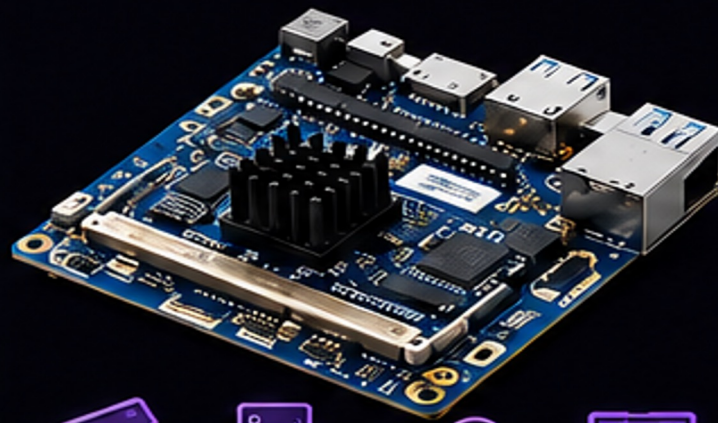
COMPACT. VERSATILE. INTELLIGENT.

- ✓ Small form factor
- ✓ Credit card-sized
- ✓ Arduino-class processing
- ✓ General-purpose computing
- ✓ AI
- ✓ Crypto

IDEAL FOR



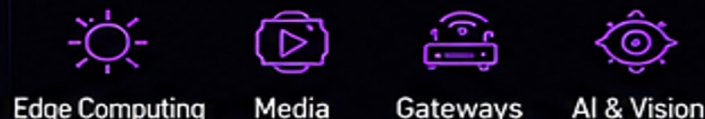
LABRADOR



POWERFUL. CONNECTED. RELIABLE.

- ✓ Medium form factor
- ✓ Credit card-sized
- ✓ PC-class processing
- ✓ General-purpose computing
- ✓ Audio and video processing
- ✓ Broadband communication

IDEAL FOR



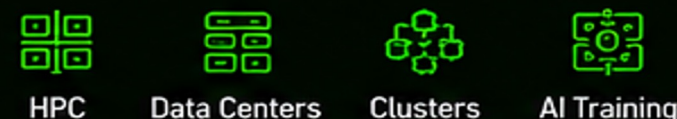
FILA



SCALABLE. HIGH-PERFORMANCE. UNSTOPPABLE.

- ✓ Large form factor
- ✓ No size constraints
- ✓ High-performance computing
- ✓ Programmable
- ✓ Co-processing
- ✓ Multiple communication channels

IDEAL FOR



SECURITY
CRYPTO READY



EFFICIENCY
LOW POWER CONSUMPTION



PERFORMANCE
FOR ANY CHALLENGE



FLEXIBILITY
FOR ANY PROJECT

DEVELOPED BY
CANINOS LOUCOS
.ORG

RISC-V edge intelligence +
memory + power management +
MEMS CO₂ sensing for long-lived
environmental probes

The Swarm Node: PULGA Microcontroller

Micro-Scale Form Factor

A 2x2 cm footprint, small enough to mount on a leaf without disrupting biomechanics.

Edge AI Ready

Equipped with 36 GPIOs and direct I2C communication for advanced VOC sensor arrays.

Heterogeneous Integration

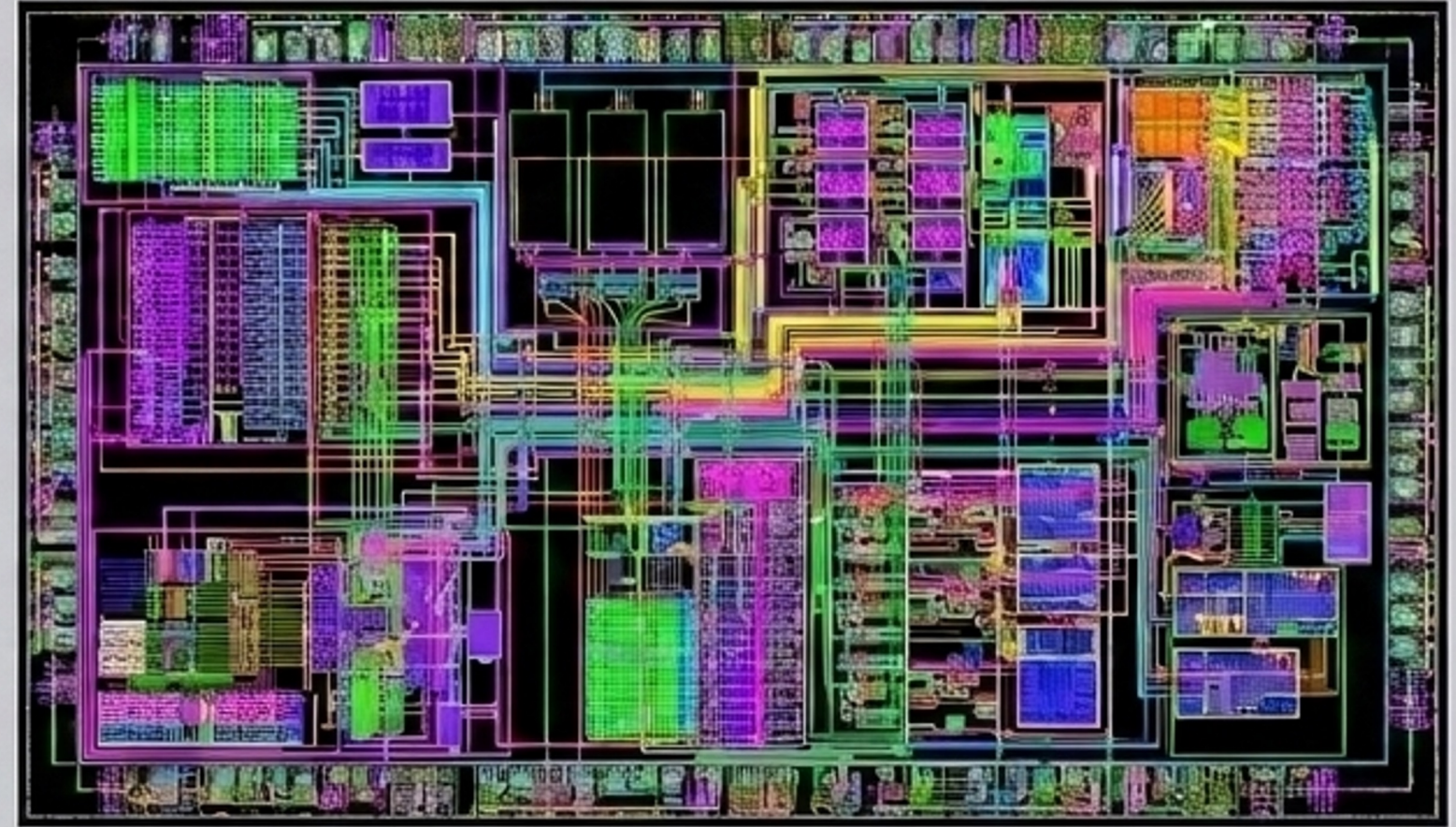
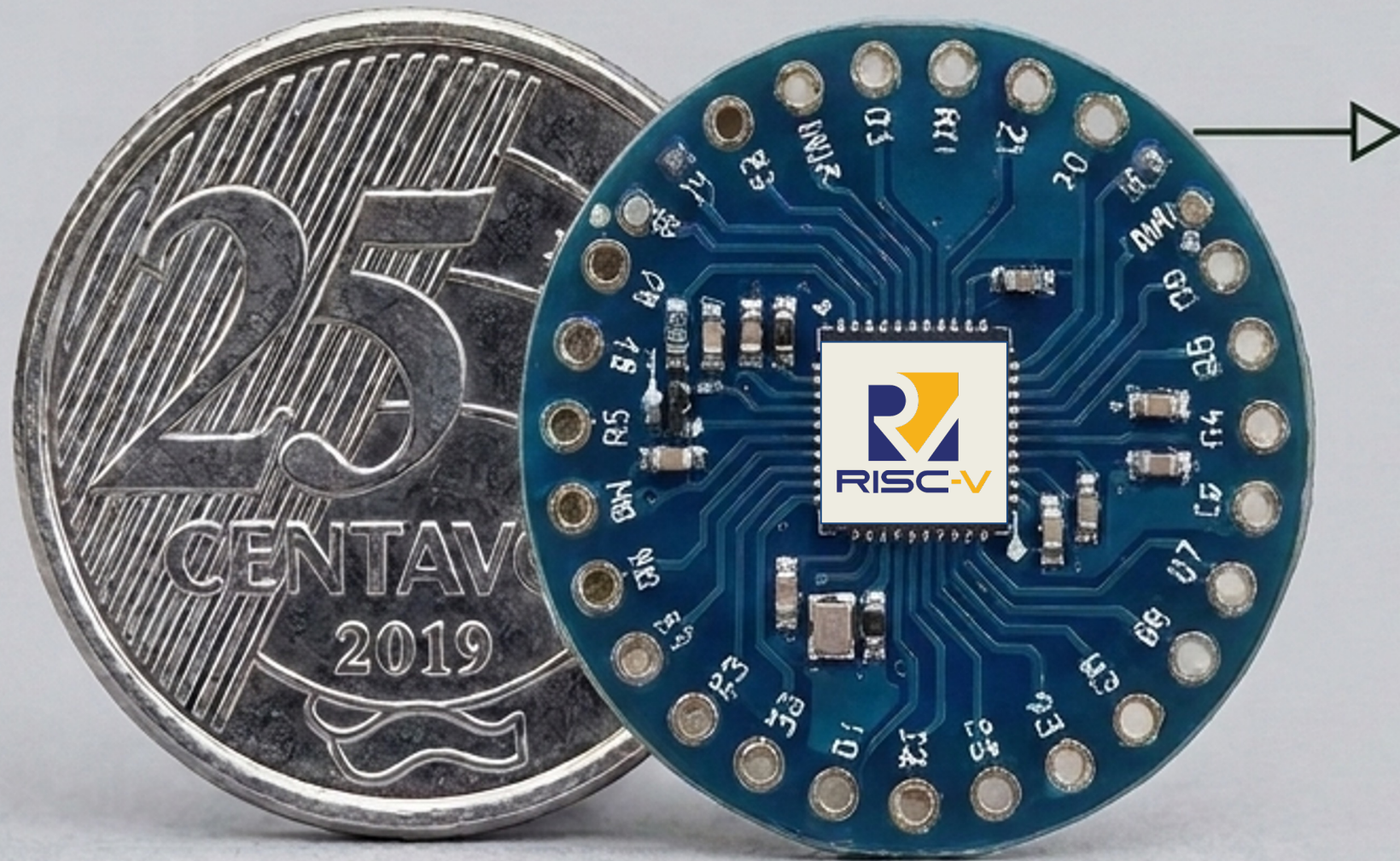
Houses both the Puppy 1.0 SoC and the K9 PMIC 1.0 on a single board.

The Building Block

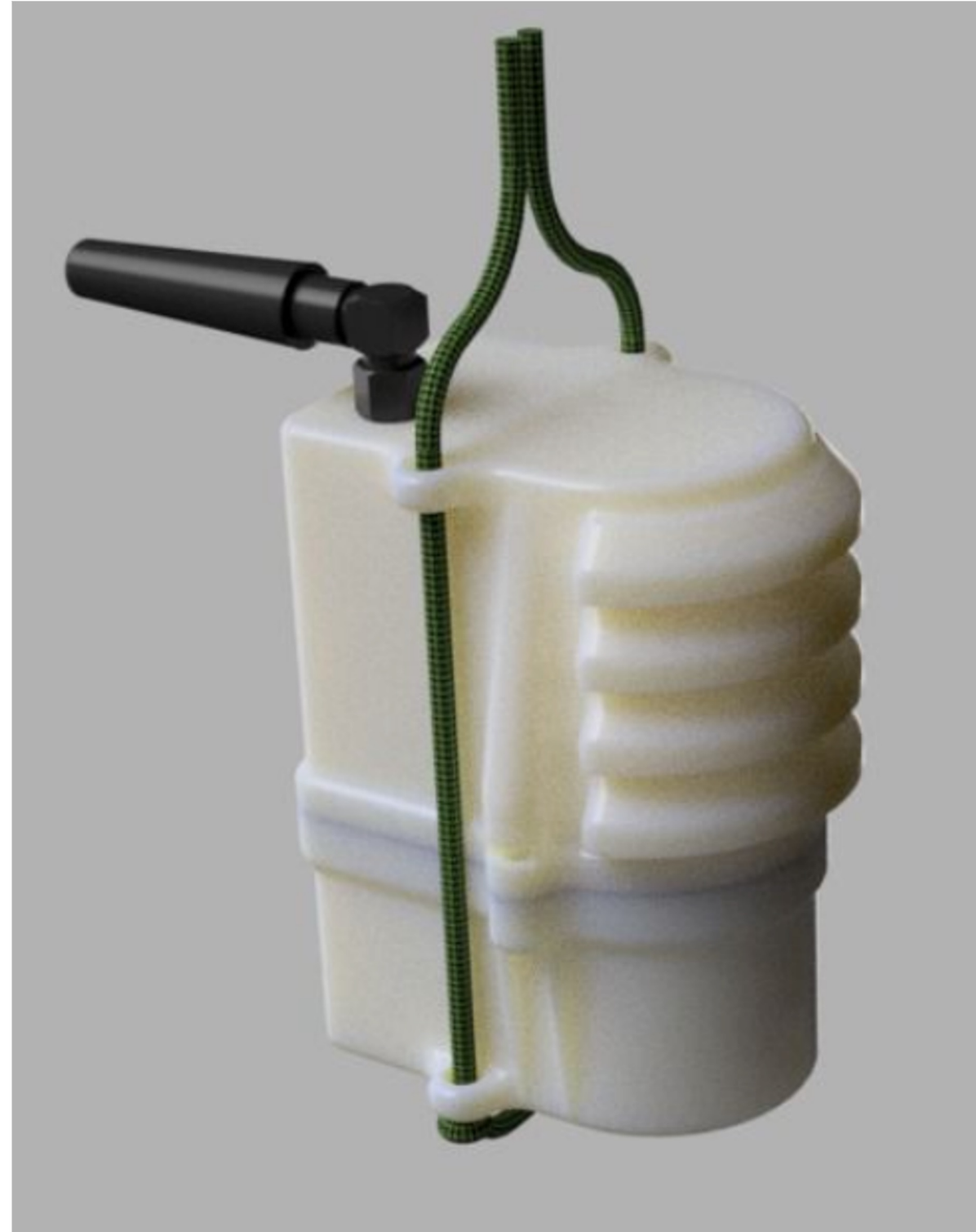
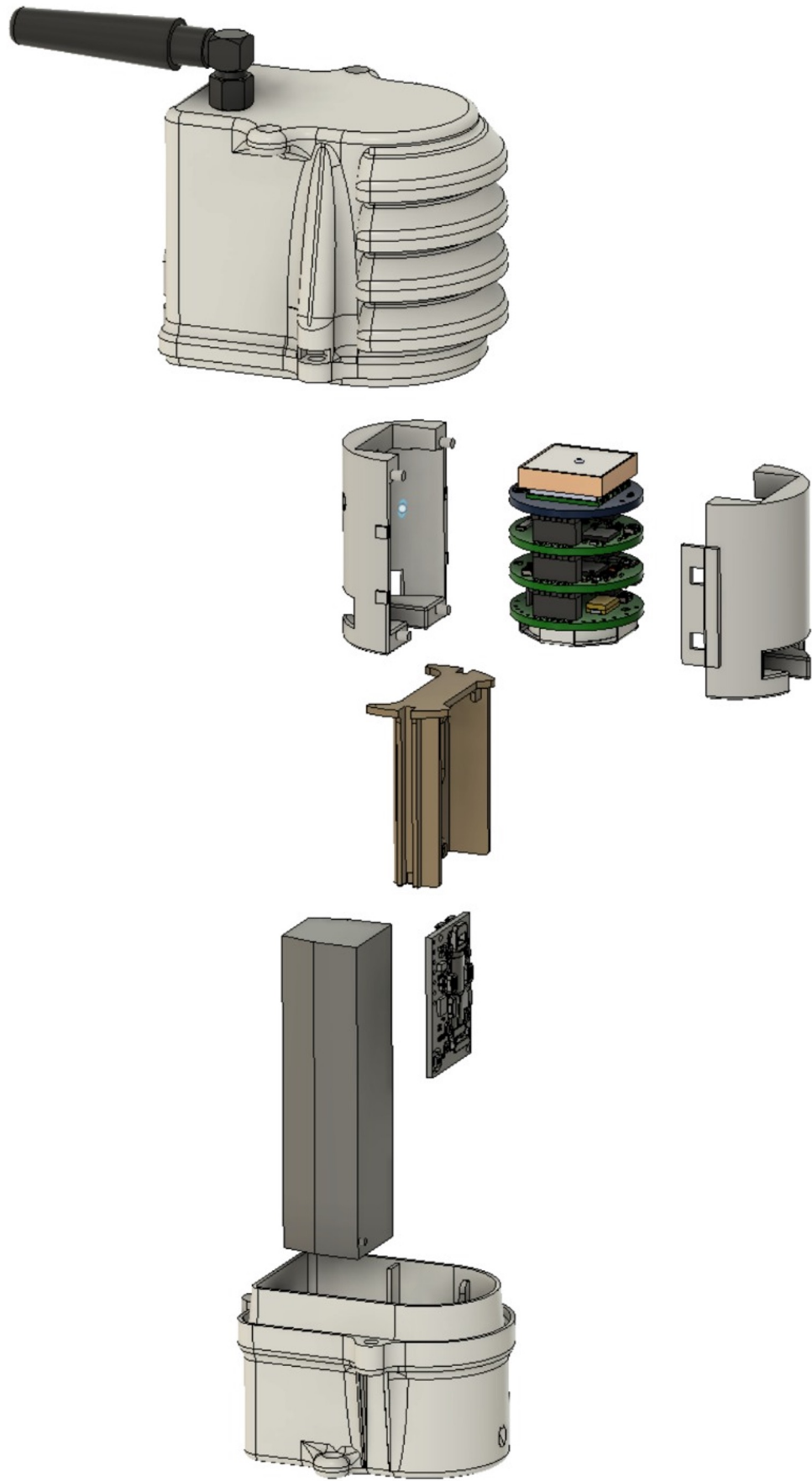
The fundamental physical unit to compose a swarm of billions.



The Core Technology: SoC Puppy and Microcontroller PULGA

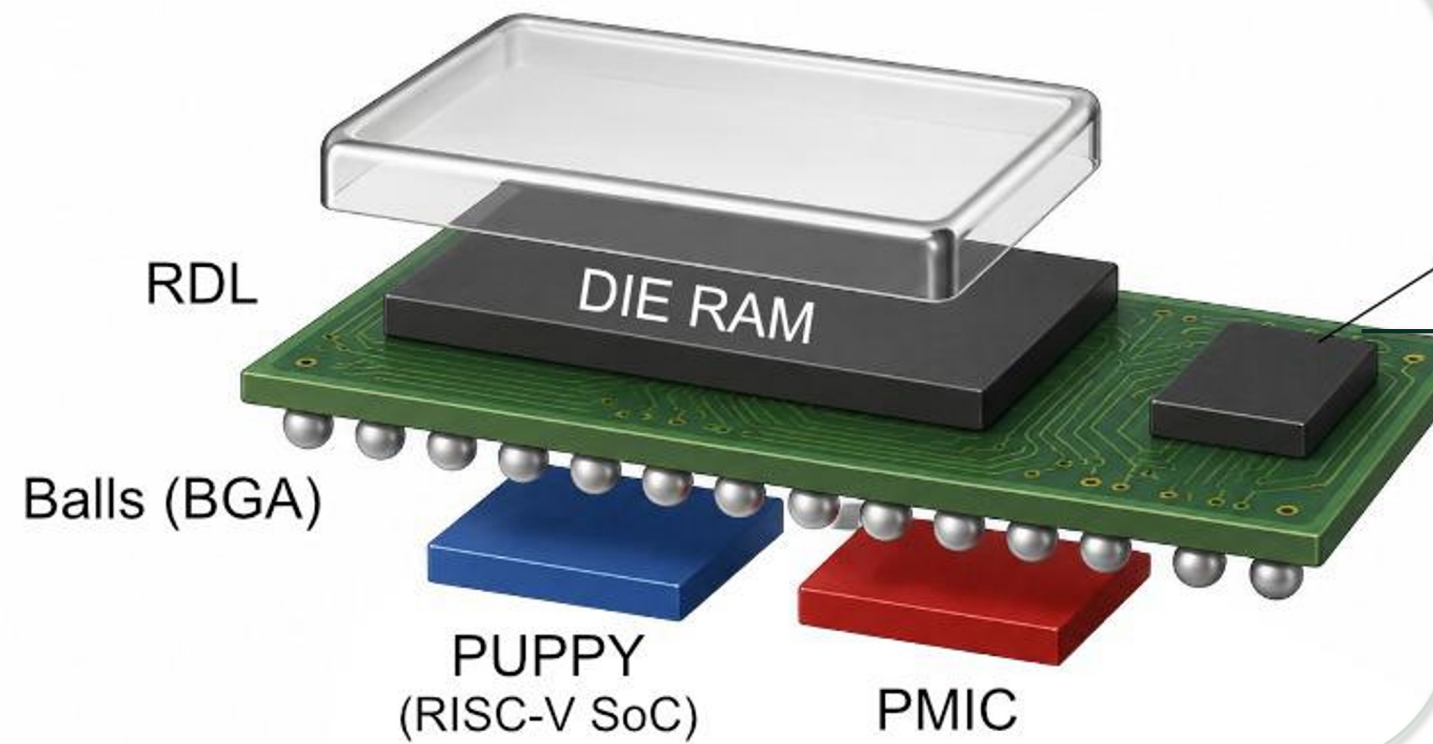


Process:	UMC 65nm
Area:	3.59 mm x 1.85 mm
Architecture:	RISC-V RV32IMCFXpulpv2
Dynamic Consumption:	13.8 mW
Acceleration:	Integrated HWPE Crypto Acceleration



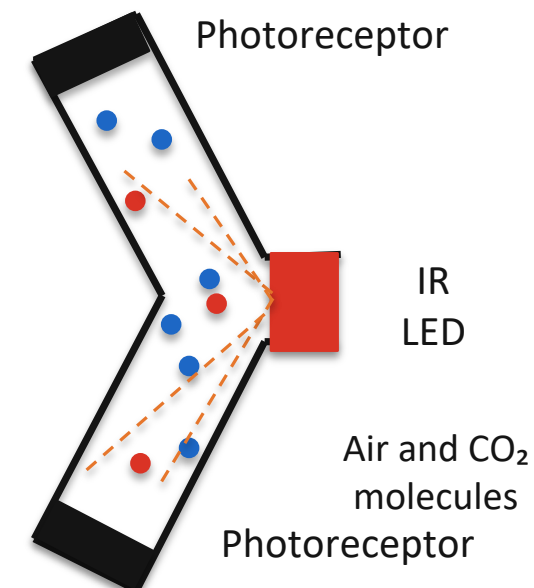
Heterogeneous Integration of the Forest Probe in a Single Package

RISC-V edge intelligence + memory + power management + MEMS CO₂ sensing for long-lived environmental probes

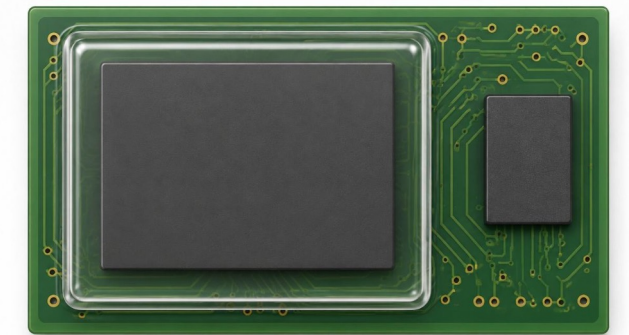


- **RDL substrate** — redistribution layer interconnecting heterogeneous dies
- **PUPPY** — open RISC-V SoC for edge computing and secure control
- **PMIC** — local power management for ultra-low-energy operation
- **RAM Die** — stacked memory protected by a transparent package cap

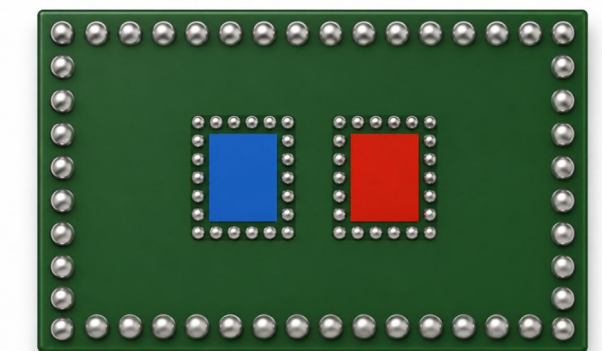
MEMS CO₂ Sensor



- Single-package forest perception node
- Open RISC-V computing for long-term autonomy
- Designed for harsh tropical environments



Top view: integrated RAM + sensor



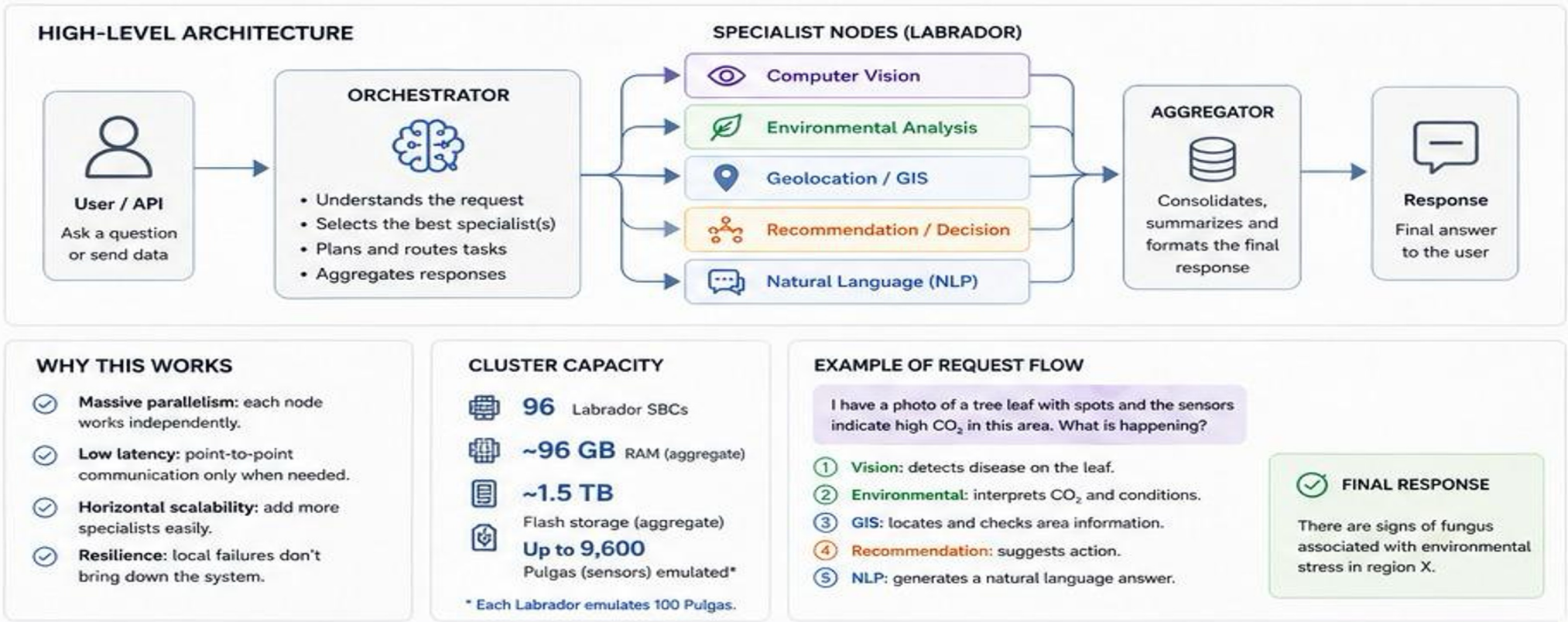
Bottom view: BGA balls and dies

AI SWARM CLUSTER ARCHITECTURE

Many specialists, one orchestrator: fast, efficient and scalable intelligence.



Physical demonstrator: AI cluster built with 96 Labrador SBC nodes.

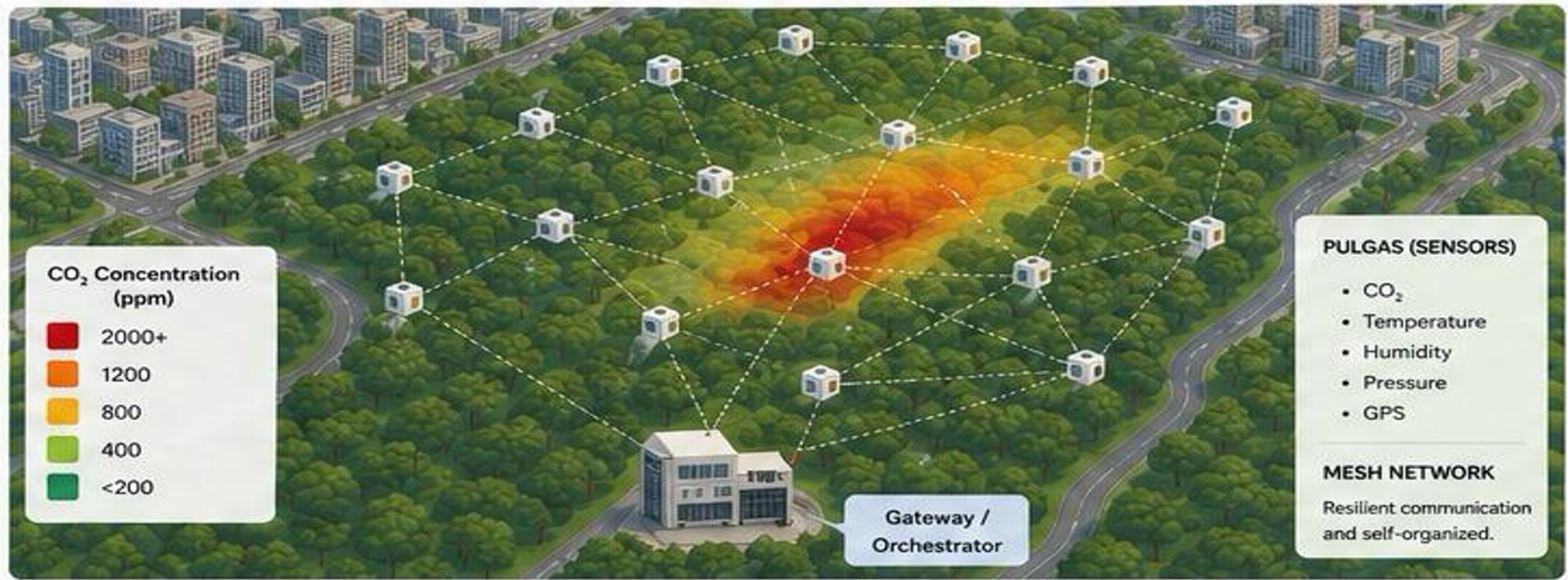


Instead of one giant model, the cluster works as an ecosystem of specialists cooperating to deliver fast, accurate and scalable answers.

Marcelo Zuffo • University of São Paulo

APPLICATION SCENARIO: URBAN FOREST MONITORING

9,600 Pulgas (sensors) distributed in an urban forest to detect and track CO₂ plumes in real time.



SPECIALISTS IN THE CLUSTER (EXAMPLES)



HOW IT WORKS

- 1 Pulgas collect and send data.
- 2 Orchestrator interprets and plans.
- 3 Data is sent to the best specialists.
- 4 Results are aggregated.
- 5 Response/alert is delivered.

BENEFITS

- ✓ Early detection of CO₂ plumes and events.
- ✓ Faster and more accurate decisions.
- ✓ Efficient use of small and specialized models.
- ✓ Scalable, resilient and low-cost system.

By emulating 9,600 Pulgas, the cluster enables realistic large-scale studies of CO₂ dispersion and supports smarter environmental monitoring.

Marcelo Zuffo • University of São Paulo

Smart Forests: The Results of Pioneering Urban Forest Monitoring

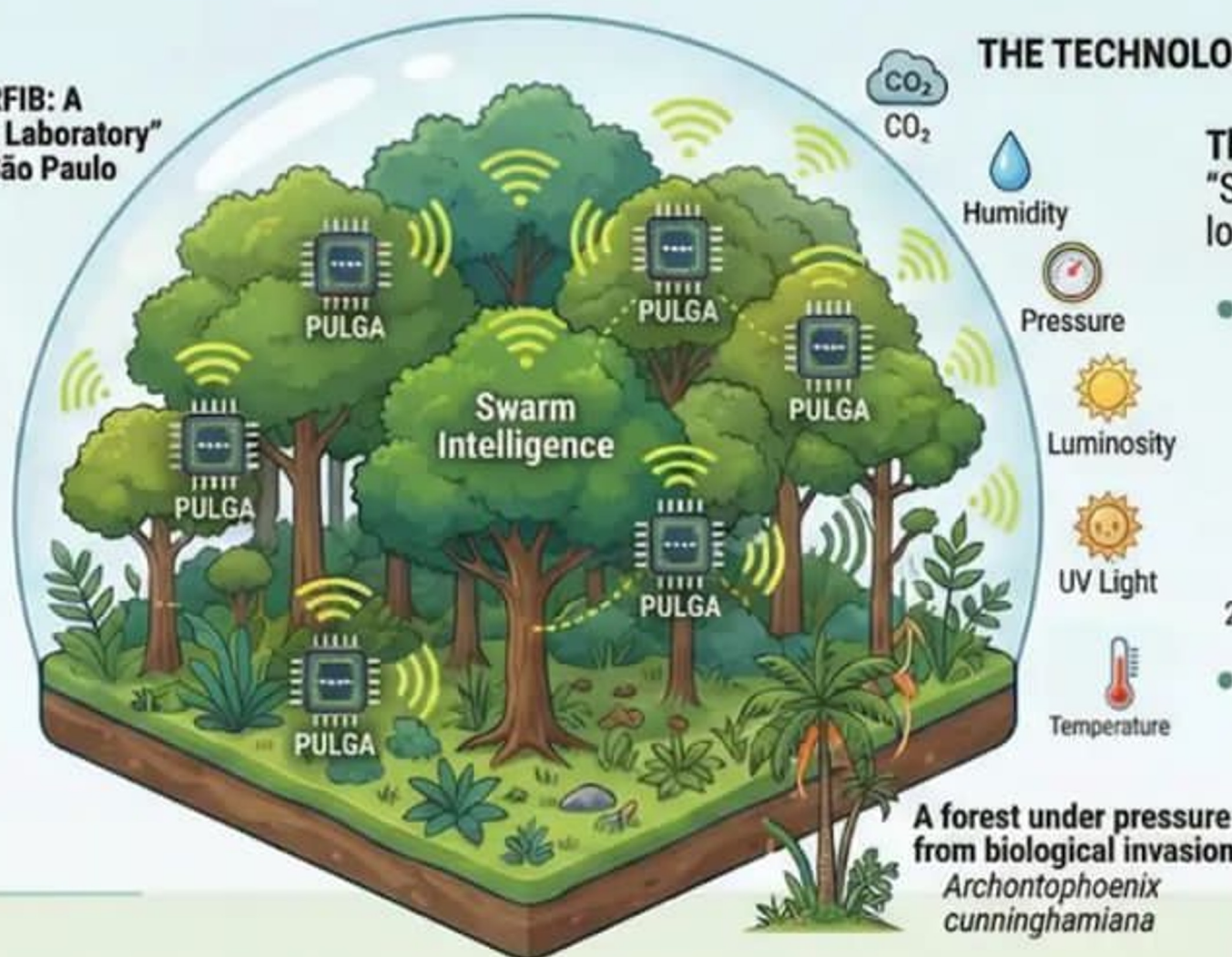
THE CHALLENGE & THE "LIVING LAB"

Cities are climate change hotspots

- The project's main study site is the 10.2-hectare Atlantic Forest fragment at USP, which is used to test and validate monitoring tools.
- The RFIB is threatened by the invasive Australian royal palm (*Archontophoenix cunninghamiana*).



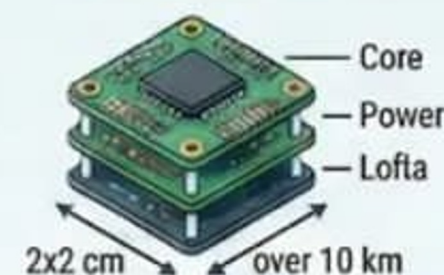
RFIB: A
"Living Laboratory"
in São Paulo



THE TECHNOLOGICAL SOLUTION: AN INTELLIGENT SENSOR NETWORK

The project created a sensor network based on "Swarm Intelligence" (IAS) for efficient, long-range, and low-power data collection.

- The core hardware is the tiny "PULGA" microcontroller



- Sensors monitor the forest's "breath"

- Firmware optimization boosted battery life by over 4000%

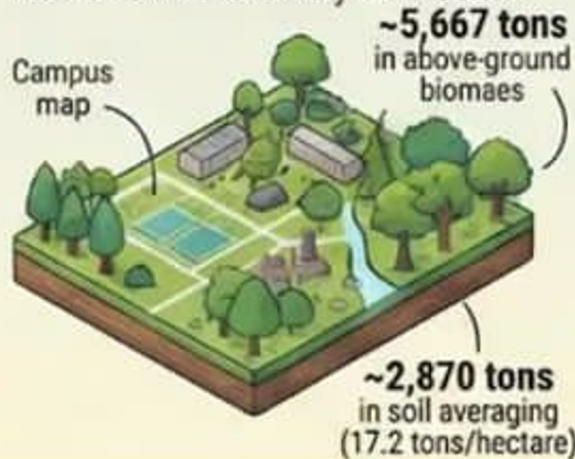


Migrating to the Zephyr RTOS and reducing sampling frequency increased battery duration from

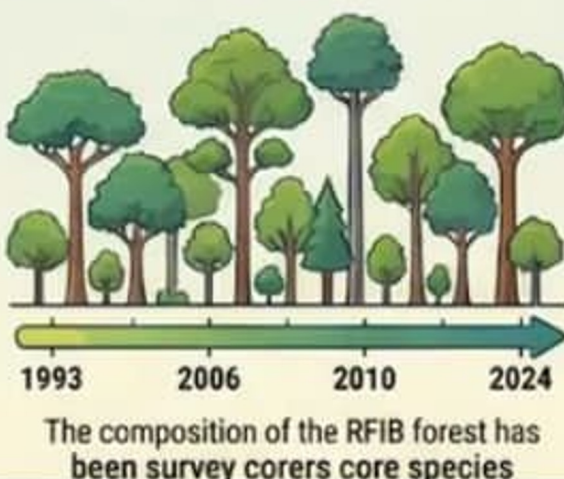
- Tests revealed that the SCD30 CO₂ sensor provides inconsistent readings below 3.3V, a critical finding that explains field failures.

KEY BIOLOGICAL & ECOLOGICAL RESULTS

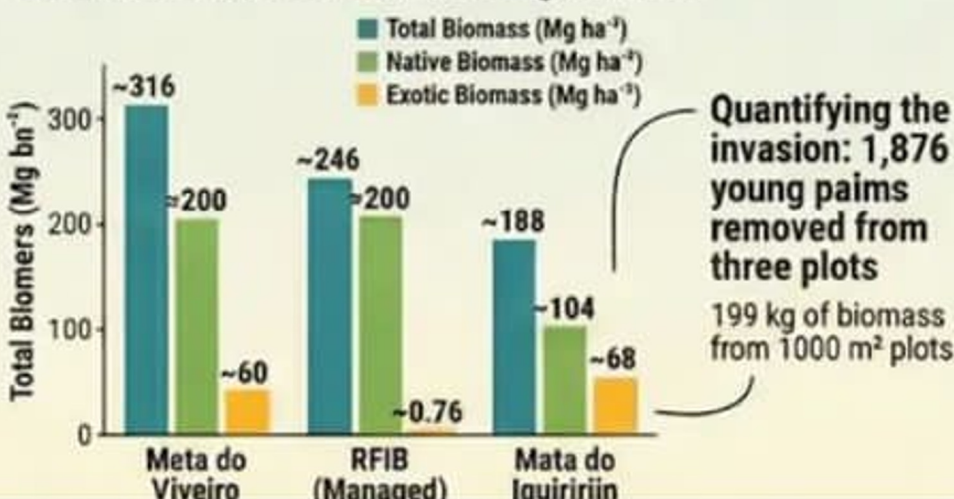
Historical analysis revealed that the core tree species composition within the reserve has remained relatively consistent.



The composition of the RFIB forest has been stable for over 30 years



Proof that management works: Invasive species biomass is 89x lower in the managed forest



DATA TOOLS AND FUTURE VISION



Interactive web dashboard developed using R Shiny Visualizing live data



Next step: Integrating Large Language Models (LLMs) Control the sensor swarm



Automated alert system Sends email alerts * sensors stop transmitting for 24 hours



Goal to expand monitoring to the Amazon and Atlantic Forest Scalable tools applied to larger biomes

Real-World Deployment: Digital Twins



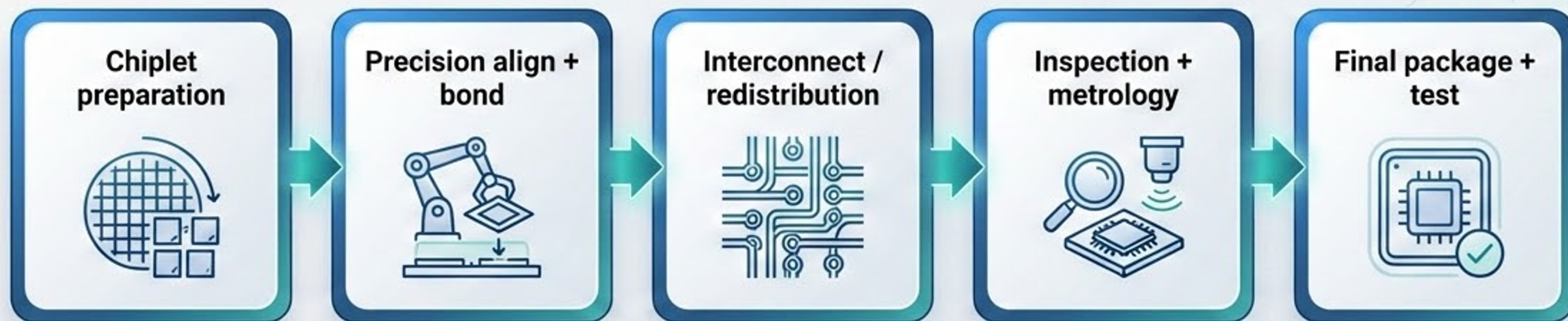
Converting billions of raw micro-points into real-time, actionable 3D canopy diagnostics.

The ultimate synthesis of the Internet of Trees: complete, persistent, and immediate planetary awareness.

Practical instantiation: a 3D chiplet packaging PocketFab

The concept is grounded in a packaging-centered, modular, end-to-end implementation.

A packaging-first PocketFab can localize the high-value stages that connect known-good chiplets into domain-specific systems.



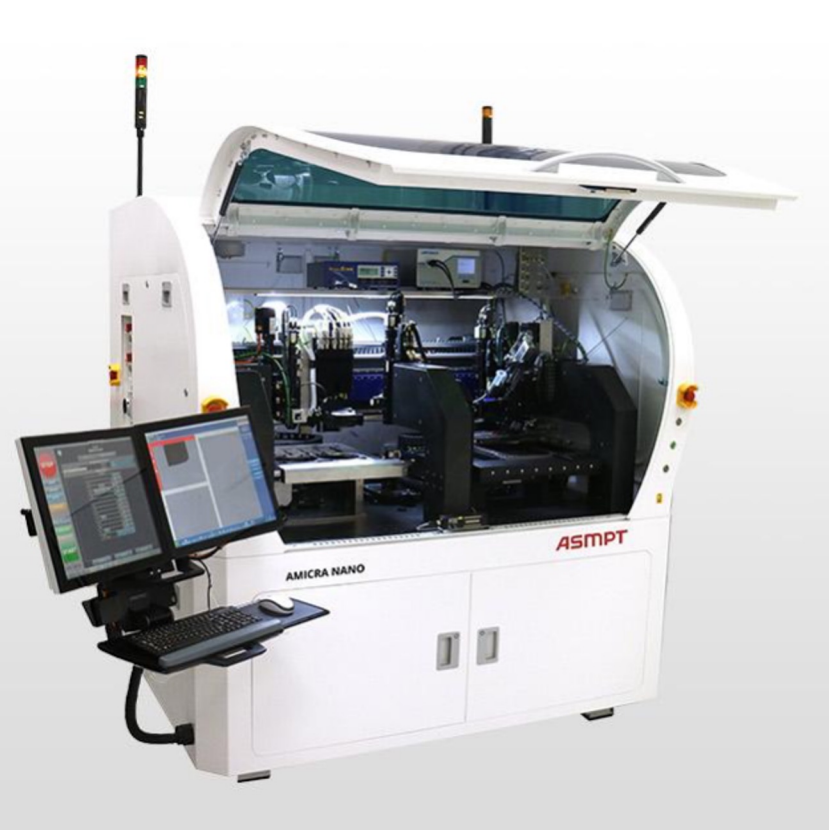
This is where PocketFab becomes actionable: not as a universal fab replacement, but as a compact architecture for heterogeneous integration, assembly, metrology, and agile system realization.

Module 1

Precision align +
bond



Interconnect /
redistribution



amicra nano
ASMPT



Optomec Aerosol Jet
HD2





Conclusion

We are not simply placing computers in the forest. We are creating a symbiotic digital perception system — a new class of long-living, low-power, open, and sovereign environmental probes designed to listen, sense, learn, and communicate with the living forest.

Open-source silicon (RISC-V) fused with organic resilience is the only scalable, sovereign, and transparent architecture for the stewardship of our planet.