From Digital Twins to Cognitive Twins:
Closing the Metacognitive Loop for 6G & Beyond Wireless Systems

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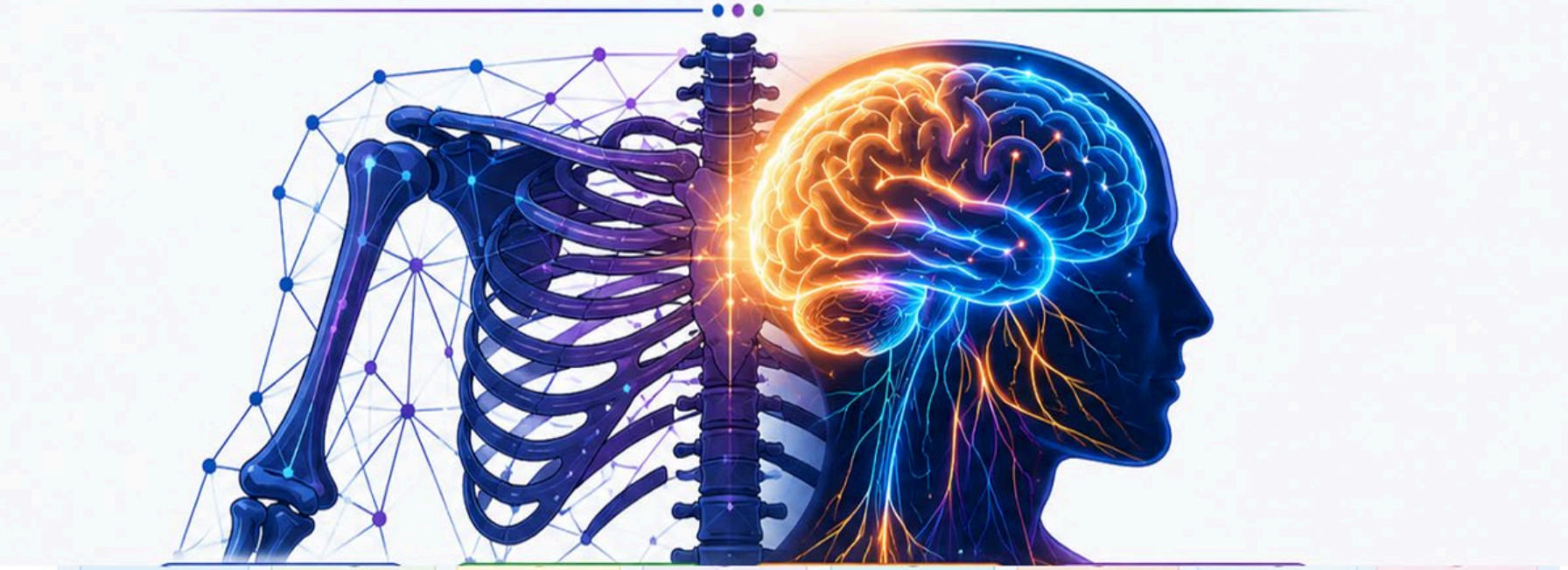
"We built the skeleton of a global network.
Now we must give it a brain and a nervous system." IFA'2026

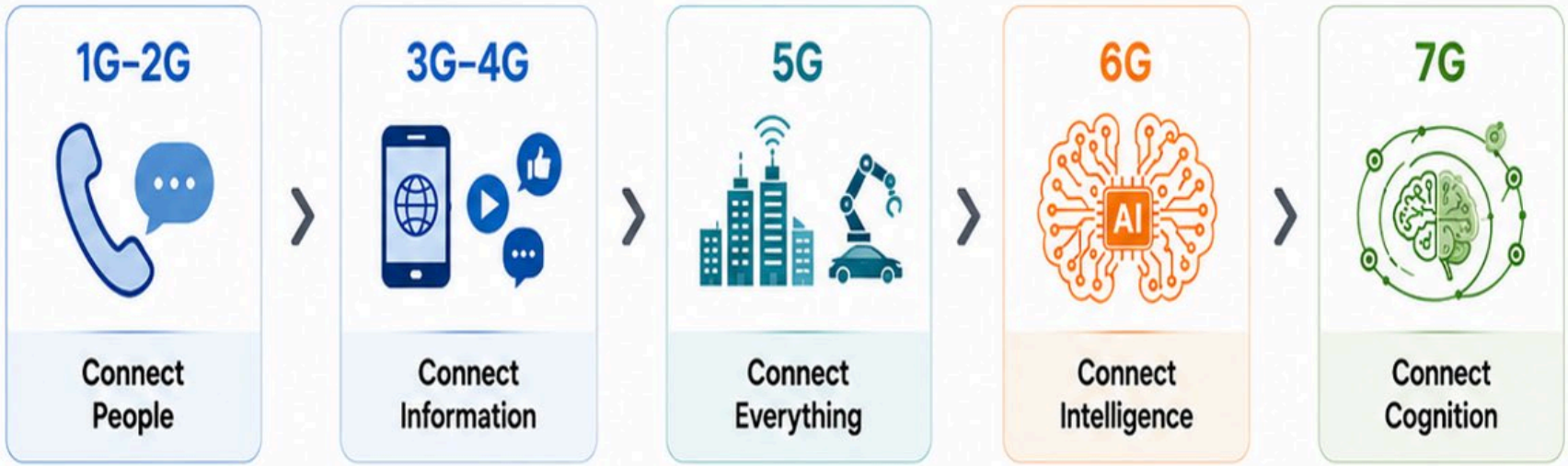


PERCEIVES → REASONS → THINKS → LEARNS → REMEMBERS → ADAPTS → EVOLVES → EXPLAINS ITSELF

COGNITIVE WIRELESS ERA

FROM CONNECTIVITY TO COGNITION

Each generation expanded what networks could do.

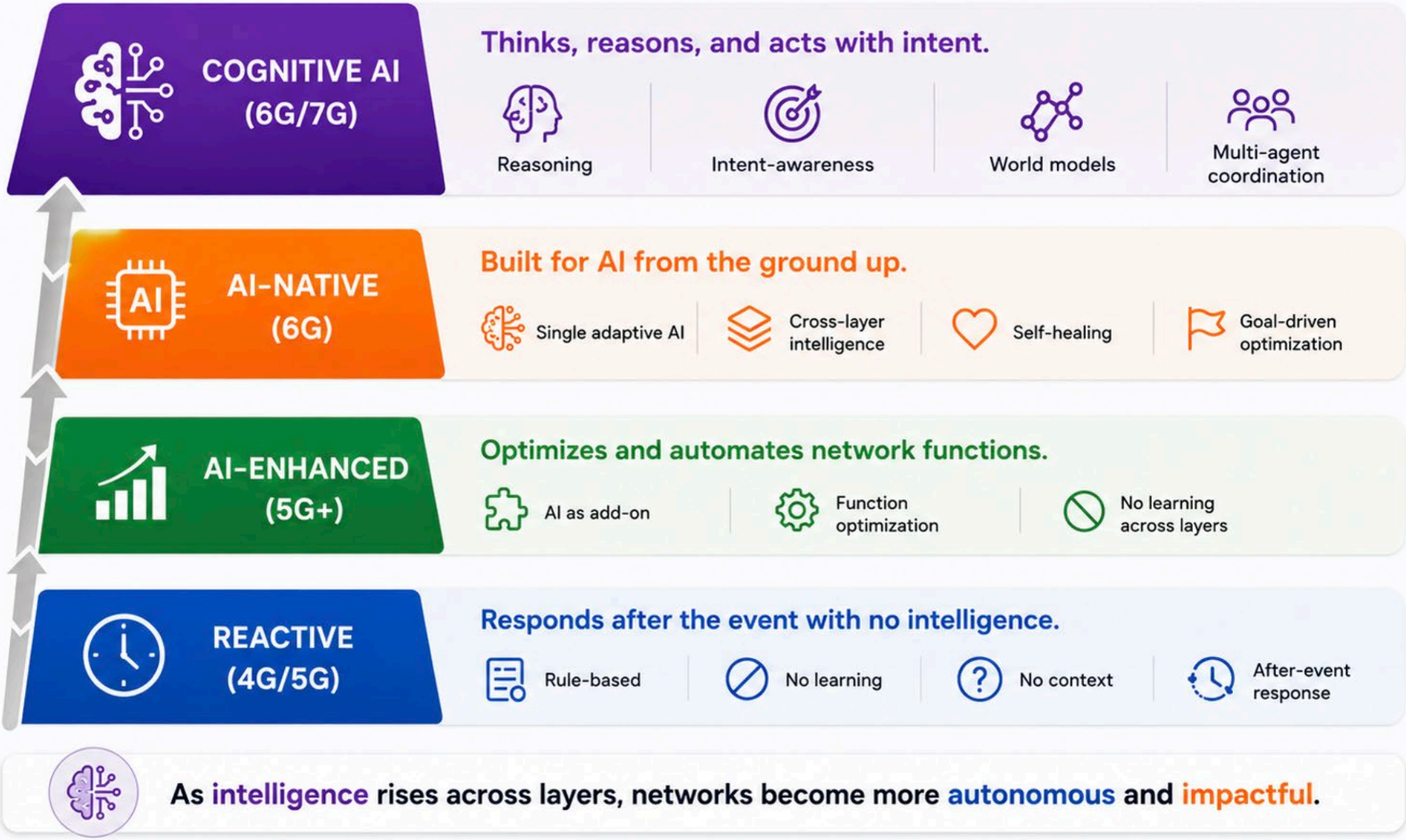


Networks are evolving from communication systems into cognitive systems.

Future systems require networks that understand intent, predict outcomes, and coordinate decisions.

THE INTELLIGENCE CLIMB OF FUTURE NETWORKS

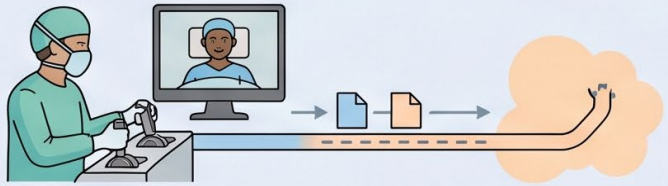
From reactive connectivity to cognitive intelligence.



From Reactive to AI-Native to AI Cognitive Networks

Example: Surgeon in Tokyo operates on patient in Kenya

Reactive Network



Then a problem appears:
Network lag suddenly jumps from 10ms to 300ms.

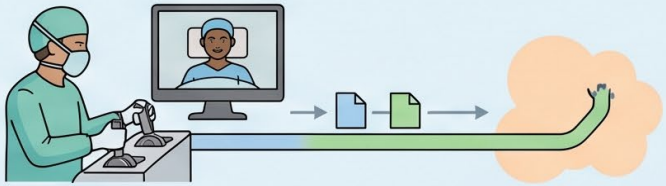
Oh, I see lag now. Let me try to fix it.
(But fixing takes 2 seconds.)

In surgery, 2 seconds = knife moves wrong = patient hurt.

- ❌ Fixes problems after damage happens
- ❌ Too slow for life-critical tasks

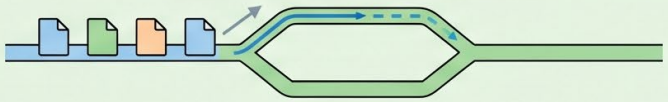
👉 Like a car airbag that opens after you already hit the tree.

AI-Native Network



Before lag happens, AI-Native predicts it:
"I see network congestion building in 500ms. I will reroute the surgery data now — before the lag hits."

It understands intent:
"This is surgery. Zero lag allowed."

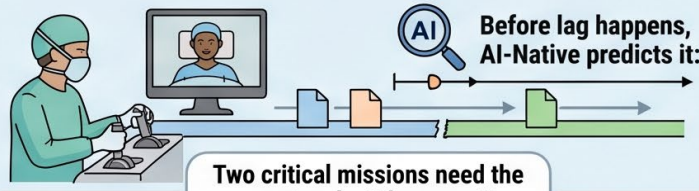


It acts proactively, not reactively.

- ✅ Predicts problems before they happen
- ✅ Understands intent (surgery = critical)

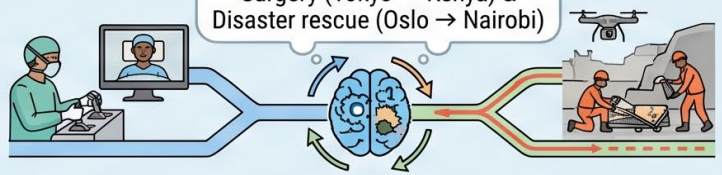
👉 Like a car that brakes automatically before you hit the deer — not after.

AI-Cognitive Network



Before lag happens, AI-Native predicts it:

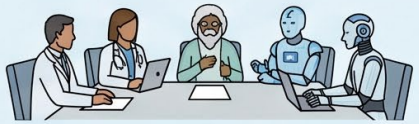
Two critical missions need the same network at the same time:
Surgery (Tokyo → Kenya) &
Disaster rescue (Oslo → Nairobi)



AI-Cognitive thinks and negotiates:
"Both are life-critical. But surgery is mid-incision.
I will give surgery 80% of bandwidth for 10 seconds,
then switch to rescue. Here is why I chose this."

It explains its decision to doctors and rescue teams.
It learns from this event for next time.

- ✅ Reasons about trade-offs
- ✅ Negotiates between conflicting life-critical tasks
- ✅ Explains itself like a human expert.



👉 Wise, collaborative decision-making, **advanced AI systems** working together.

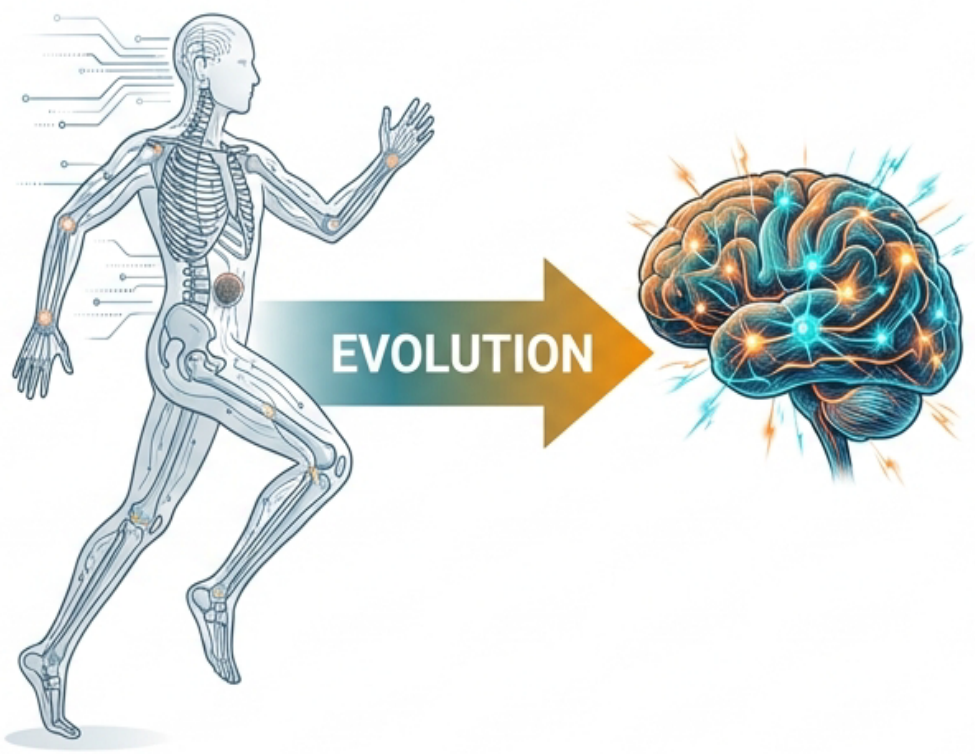
FROM AI-NATIVE TO COGNITIVE AI NETWORKS

From intelligence as a feature to intelligence as a nervous system

AI-Native Network (6G) — AI as Core

- Goal-Oriented & Context-Aware
- AI Built into All Layers (PHY to APP)
- Single Integrated Learning System (Learns from Data)
- Self-Optimizing (Latency, Reliability, Energy)
- Proactive: intent-aware, grasp human goals, causal reasoning

AI-NATIVE: Brilliant memorization and optimization



Cognitive Wireless Network (7G) — Network as a Nervous System

- Fully Prescriptive: closes the loop (predict → prescribe → act)
- Self-Evolving Architecture: no human upgrades — rewires itself over time
- Distributed Cognition: every node thinks — no central bottleneck
- Neuro-Symbolic AI: pattern matching + logic = true reasoning
- Incremental + Meta-Learning: learns continuously, doesn't forget, learns how to learn

COGNITIVE = A nervous system that truly thinks

Self-Evolving / Distributed Cognition

NERVOUS SYSTEM OF EVERYTHING

One Cognitive Twin is a brain. Many Connected Brains = **A Nervous System for the Real World**

DIGITAL TWIN: BLUEPRINT

Represents the world

STATIC
Predefined models

ACCURATE
High-fidelity representation

COGNITIVE TWIN: BRAIN

Understands and reasons

LEARNS
From data, experience & feedback

ADAPTS
Continuously to change

NERVOUS SYSTEM OF EVERYTHING

Distributed intelligence at scale

SENSES
Observe continuously from all places

RESPONDS
Instantly, everywhere, in context

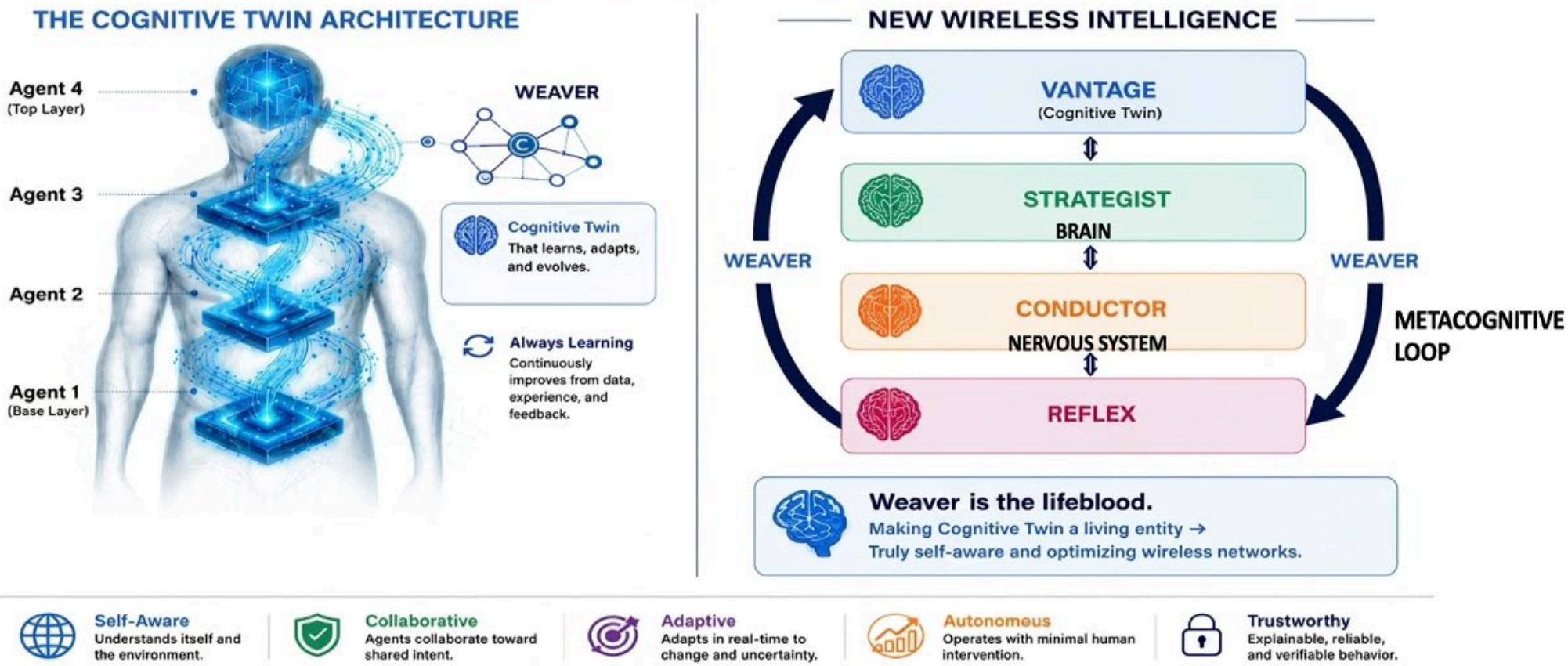
Passive long-term simulations
What-if analysis, planning, and offline evaluation

Active, thinks, learns, predicts failures, makes decisions
Real-time cognition & decisioning

Sensing, processing, and responding everywhere
Autonomous • Real-time • Scalable

From passive models → to intelligent brains → to a living nervous system of everything
Multiple cognitive twins working together as one — perceiving, understanding, reasoning, and acting in the real world.

COGENT: Cognitive Agents for Collaborative Intent



Think of this as the nervous system of a human being mapped to a network

**All agents share one Metacognitive Loop —
the Weaver watches all, the Vantage remembers all, the Reflex acts on all.**

I. F. Akyildiz and Tugce Bilen, "COGENT-Wireless: Hierarchical Cognitive Agents for Intent-Driven Autonom Beyond 6G Systems", submitted in June 2026.

THE FIVE COGNITIVE AGENTS

One thinking network built from five agents, five timescales, one continuous feedback loop

WEAVER — The Wisdom *(continuous, cross-agent)*

Watches every agent at once, metalearns across them, and continuously improves the whole system — the metacognitive layer that ties the network together.

VANTAGE

The Memory

HOURS – DAYS

- Simulates and predicts future network states
- Learns from historical + real-time telemetry

Feeds: Strategist & Conductor

STRATEGIST

The Brain

MINUTES – HOURS

- Turns human intent into network strategy
- Negotiates goals, SLAs & priorities

Feeds: Conductor

CONDUCTOR

The Nervous System

MS – SECONDS

- Executes strategy in real time
- Orchestrates beams, routing, handovers, slicing

Feeds: Reflex

REFLEX

The Muscle Memory

MICROSECONDS

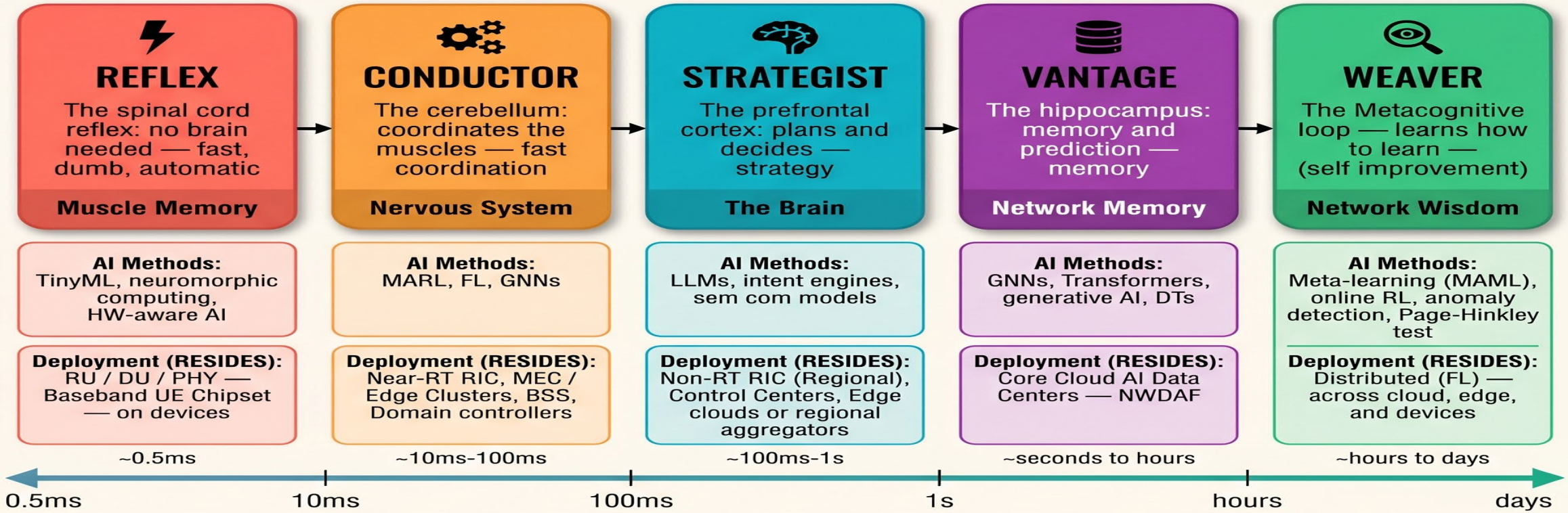
- Reacts instantly — no reasoning involved
- Local channel, power, MCS & HARQ decisions

Closes the loop back to Conductor

Five agents, one cognitive loop — each fast enough for its job, all coordinated by Weaver.

COGENT: THE FIVE-AGENT COGNITIVE ARCHITECTURE

One architecture — five agents — five timescales — from muscle memory to strategic vision

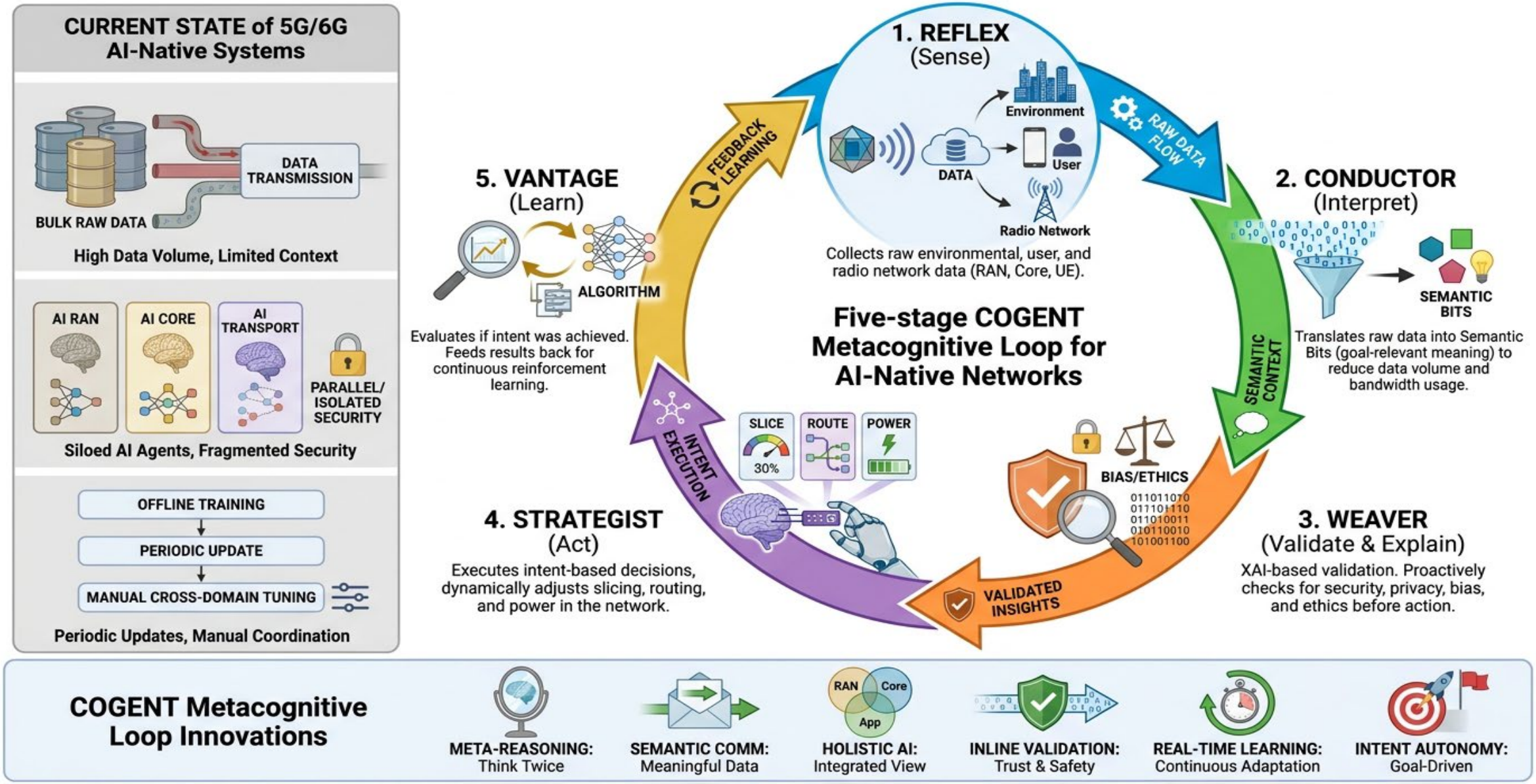


NO OTHER ARCHITECTURE SPANS THIS RANGE: FROM A 0.5 MS REFLEX TO A MULTI-DAY LEARNING CYCLE IN A SINGLE UNIFIED COGNITIVE SYSTEM.

A HIERARCHY OF INTELLIGENCE: CLOUD THINKS. EDGE COORDINATES. HARDWARE REACTS. WEAVER LEARNS IT ALL.

COGENT UNDERSTANDS: INTENTION (WHAT USER WANTS) | CAUSALITY (WHY THIS HAPPENED) | SALIENCE (WHAT MATTERS NOW) | UNCERTAINTY (WHAT IT DOESN'T KNOW).

METACOGNITIVE LOOP



BEFORE:
Failures & Inefficiency

Failures = Hours of Downtime

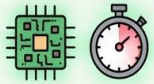
Static, wasteful
resource allocation

Reactive

One giant AI model tries
to do everything

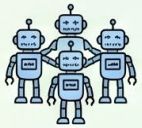
Devices need full AI capability;
expensive HW upgrades

AFTER COGENT:
Self-healing Autonomy & Optimization


Self-healing autonomy (ms-secs)

AI Optimization;
energy savings

Predictive


Five specialized agents each
with its own timescale

Legacy device support via cognitive
wrappers; no HW upgrades needed

Lower cost, less waste,
longer battery life

Proactive security

This is not incremental improvement. This is a leap.

GRAND CHALLENGES

What must we solve to make this vision real?

THE SCALABILITY PROBLEM

Can we build AI that is fast, light, and smart enough for the real world?

THE TRUST PROBLEM

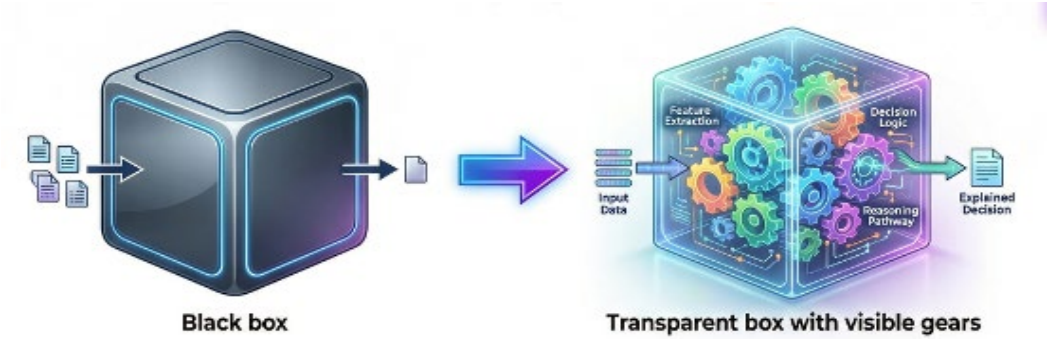
Can we trust the decisions these AI systems make?

THE INTEGRATION PROBLEM

Can we weave this intelligence into the world that already exists?

GRAND CHALLENGE: The Trust Problem

Can we trust the decisions these AI systems make?



Explainable AI (XAI)

Build AI that can explain and justify the decisions

Improve transparency of black box models

Privacy

Implement FL and differential privacy

Trustworthy AI for Security & Robustness

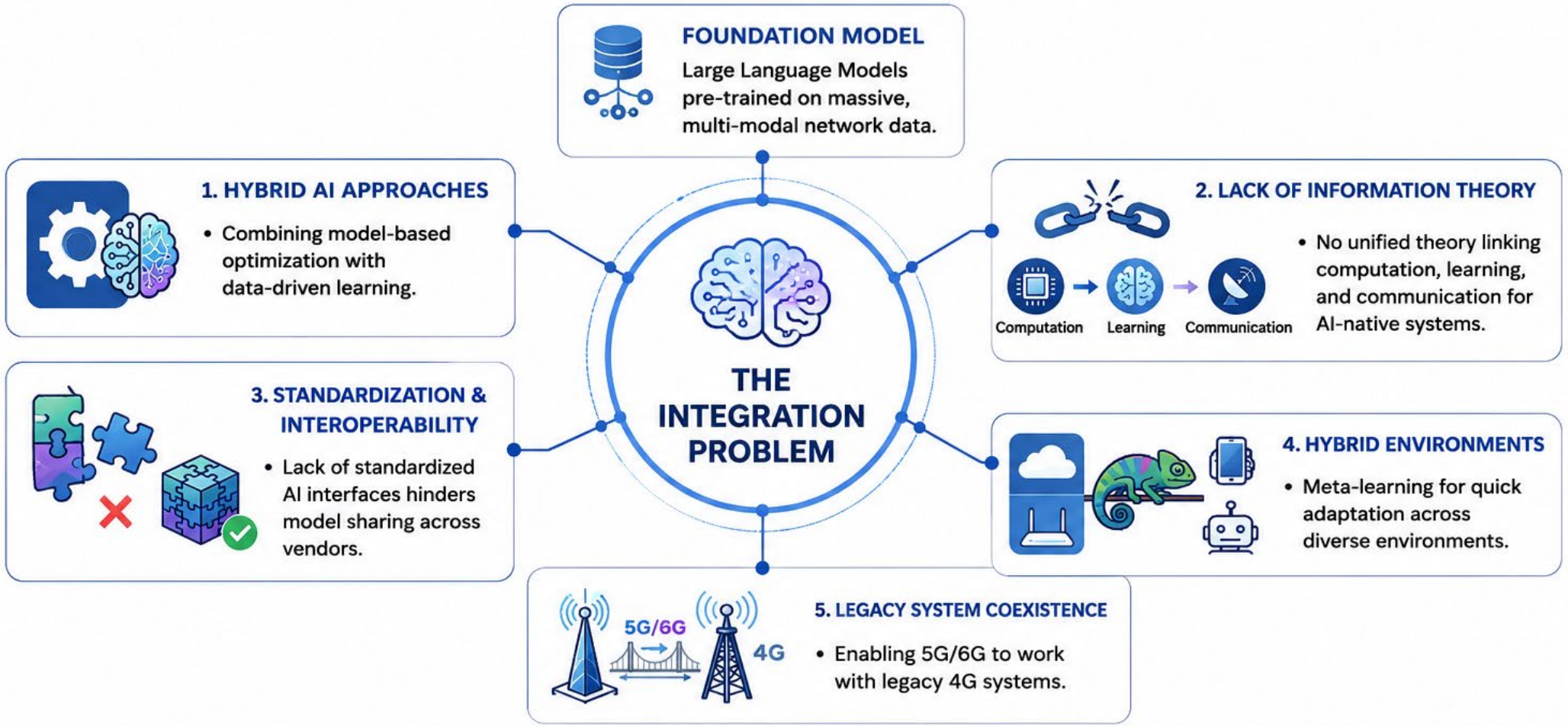
Protecting ML systems against adversarial attacks

Ethics & Fairness

Addressing bias, fairness & accountability in AI –driven systems

GRAND CHALLENGE: The Integration Problem

Can we weave this new intelligence into our existing world?



Integration is the bridge between today's systems and tomorrow's intelligence.

Interoperable | Adaptive | Scalable | Future-Ready | Built for the Real World

ETHICS & STANDARDS

REGULATORY REALITY CHECK FOR COGNITIVE NETWORKS

1. EU AI ACT

HIGH-RISK AI SYSTEMS

Purpose: Ensure safe, transparent and accountable AI in the EU.

2. STANDARDS GAP

NO STANDARD TODAY

Goal: Create open, interoperable and secure standards for cognitive networks.

3. LIABILITY & GOVERNANCE

LIABILITY GAP

If two agents disagree and a packet drops, who is legally responsible?
The carrier? The AI vendor? No answer today.

No legal framework for multi-agent decisions.

KEY OPEN QUESTIONS

- How do we ensure human oversight without killing autonomy and speed?
- How do we design standards that are future-proof, global and technology-neutral?
- How do we define liability in a world of autonomous AI agents?
- How do we align innovation speed with regulatory readiness?

Cognitive networks are advancing faster than the regulatory systems designed to govern them.

COGENT ROADMAP

Phase 1: Foundation (2025–2028)

- Single-domain **COGENT**
- **VANTAGE + REFLEX** prototype
- **WEAVER** overlay for monitoring
- O-RAN integration: **STRATEGIST** as rApp, **REFLEX** on O-DU

Standardization

3GPP Rel. 19/20

O-RAN WG11

Phase 2: Integration (2028–2032)

- Full five-agent hierarchy
- **Metacognitive Loop** fully operational
- Multi-domain pilot (terrestrial + satellite)
- O-RAN enhancement: **CONDUCTOR** as xApp, cross-RIC **WEAVER**

Standardization

3GPP Rel. 21/22

ITU-R IMT-2030

Phase 3: Maturity (2032–2040)

- Full sea-to-space **COGENT**
- UDA, NPT, Shared Cognitive Ontology
- **Foundation Model for Wireless Networks**
- O-RAN cognitive extension standardized

Standardization

ITU-R WRC-27

CCSDS

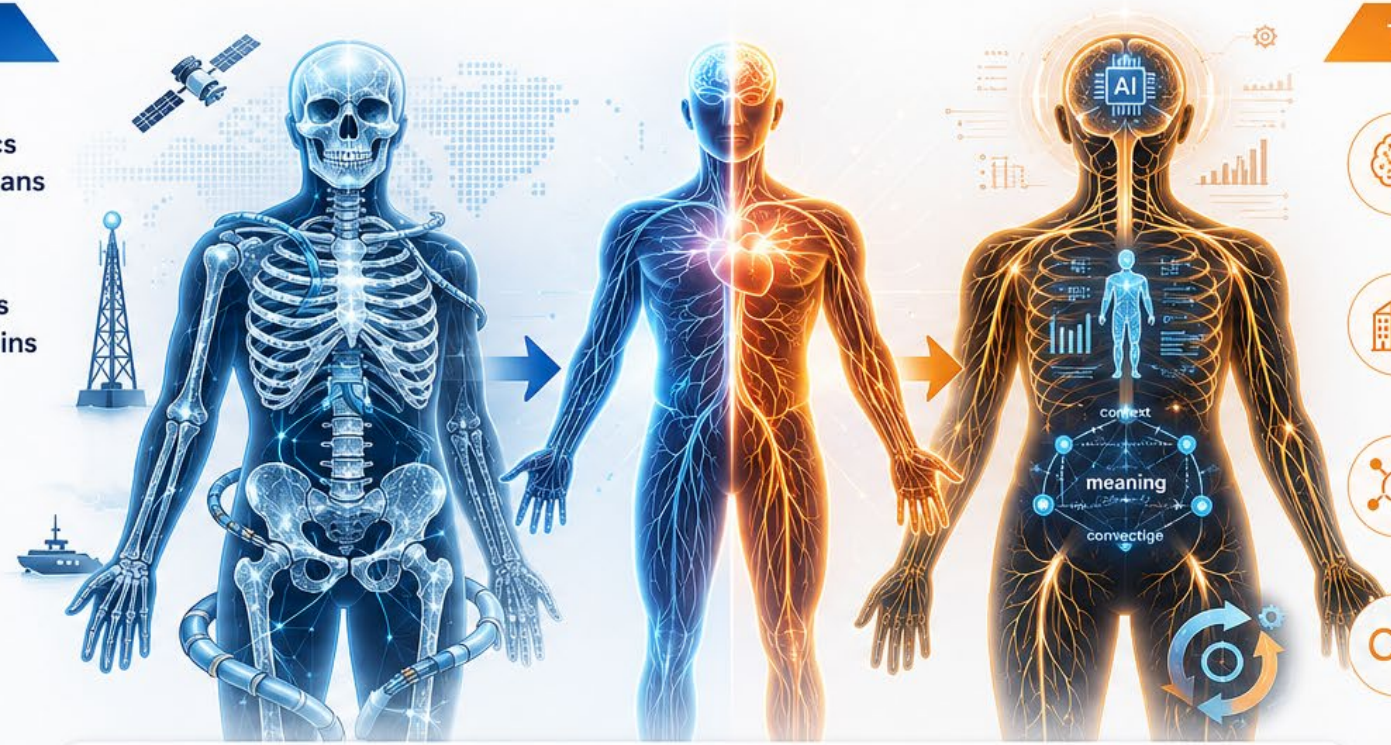
3GPP Rel. 23+

A FINAL THOUGHT

We have built the skeleton of a global network.
Now, we must give it **a brain** and **a nervous system**.

THE SKELETON:

- Fiber optics across oceans
- Cell towers on mountains
- Satellites in orbit
- Undersea cables in the deep

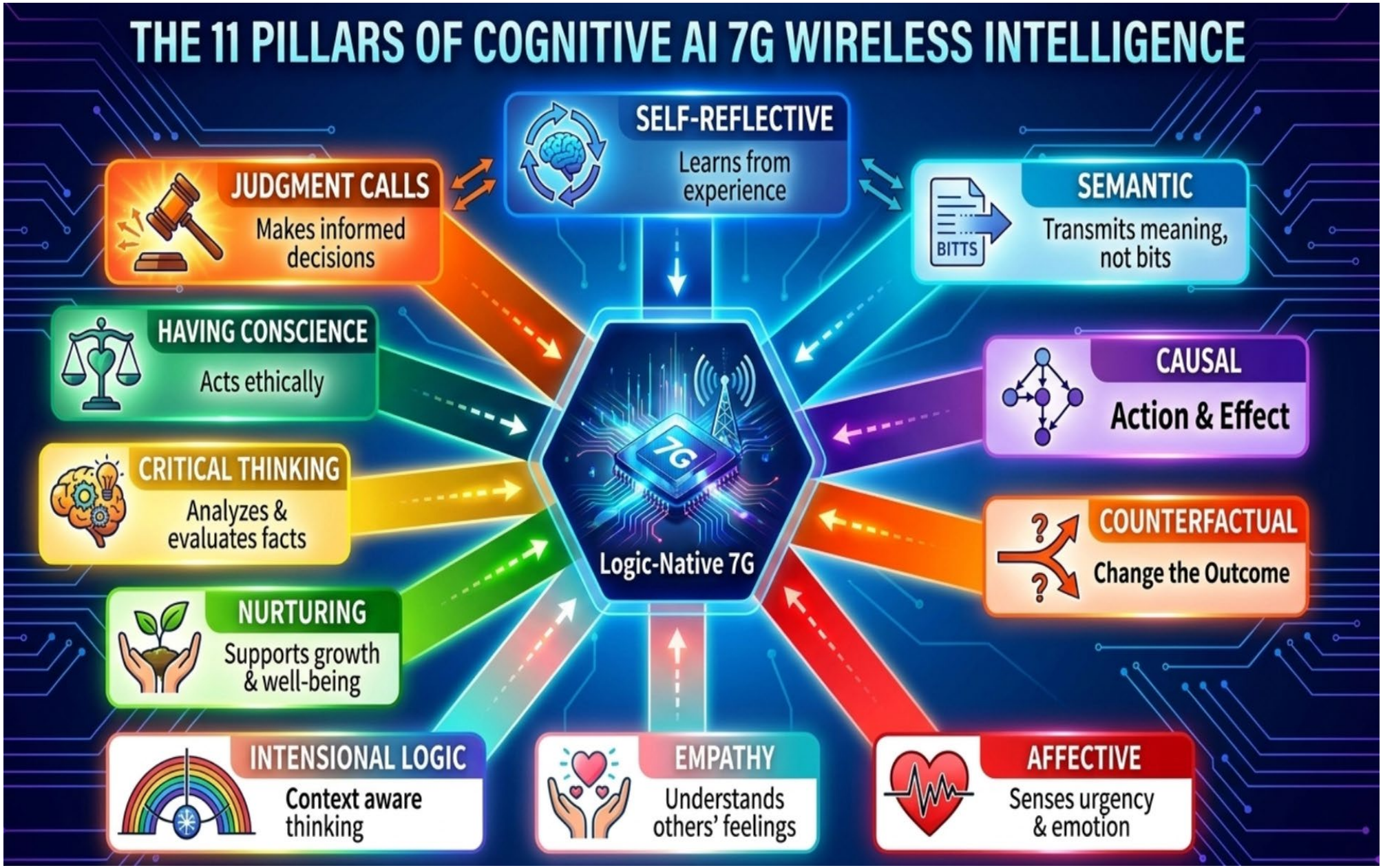


THE NERVOUS SYSTEM:

- AI that learns and adapts
- Digital twins that simulate and predict
- Semantic understanding that captures meaning
- Metacognitive loops that evolve

When we connect skeleton to nervous system,
we create something new: **a living, thinking digital world.**

> *We built the network to connect people. Now we must **teach it to think;** not because it's cool, but because the world is **too fast, too deep,** and **too complex** for us to manage alone.*
>
> — IFA'2026


THE 11 PILLARS OF COGNITIVE AI 7G WIRELESS INTELLIGENCE
SELF-REFLECTIVE
Learns from experience
JUDGMENT CALLS
Makes informed decisions
SEMANTIC
Transmits meaning, not bits
BITTS
HAVING CONSCIENCE
Acts ethically
CAUSAL
Action & Effect
CRITICAL THINKING
Analyzes & evaluates facts
COUNTERFACTUAL
Change the Outcome
7G
Logic-Native 7G
NURTURING
Supports growth & well-being
INTENSIONAL LOGIC
Context aware thinking
EMPATHY
Understands others' feelings
AFFECTIVE
Senses urgency & emotion