From Context to Consciousness: A Journey in AI Innovation

Selected Scientific Contributions of Vagan Terziyan et al.

This presentation chronicles a multi-decade research program dedicated to advancing Artificial Intelligence. The journey moves from the fundamental challenge of representing a complex world to the creation of autonomous, resilient, and symbiotic systems, culminating in a vision for the future of ethical and self-evolving intelligence.

The Ascent of Intelligence: A Five-Act Journey

Act V:
The Next Frontier of AI:
What are the ultimate destinations for intelligent systems?

Act IV:
Forging Resilient Intelligence:
How do we make AI robust, secure, and trustworthy?

Act III:
The Human-AI Symbiosis:
How do we merge human and machine intelligence?

Act II:
The Spark of Autonomy:
How do we make knowledge act and decide?

Act I:
The Architecture of Knowledge:
How do we represent a complex world?

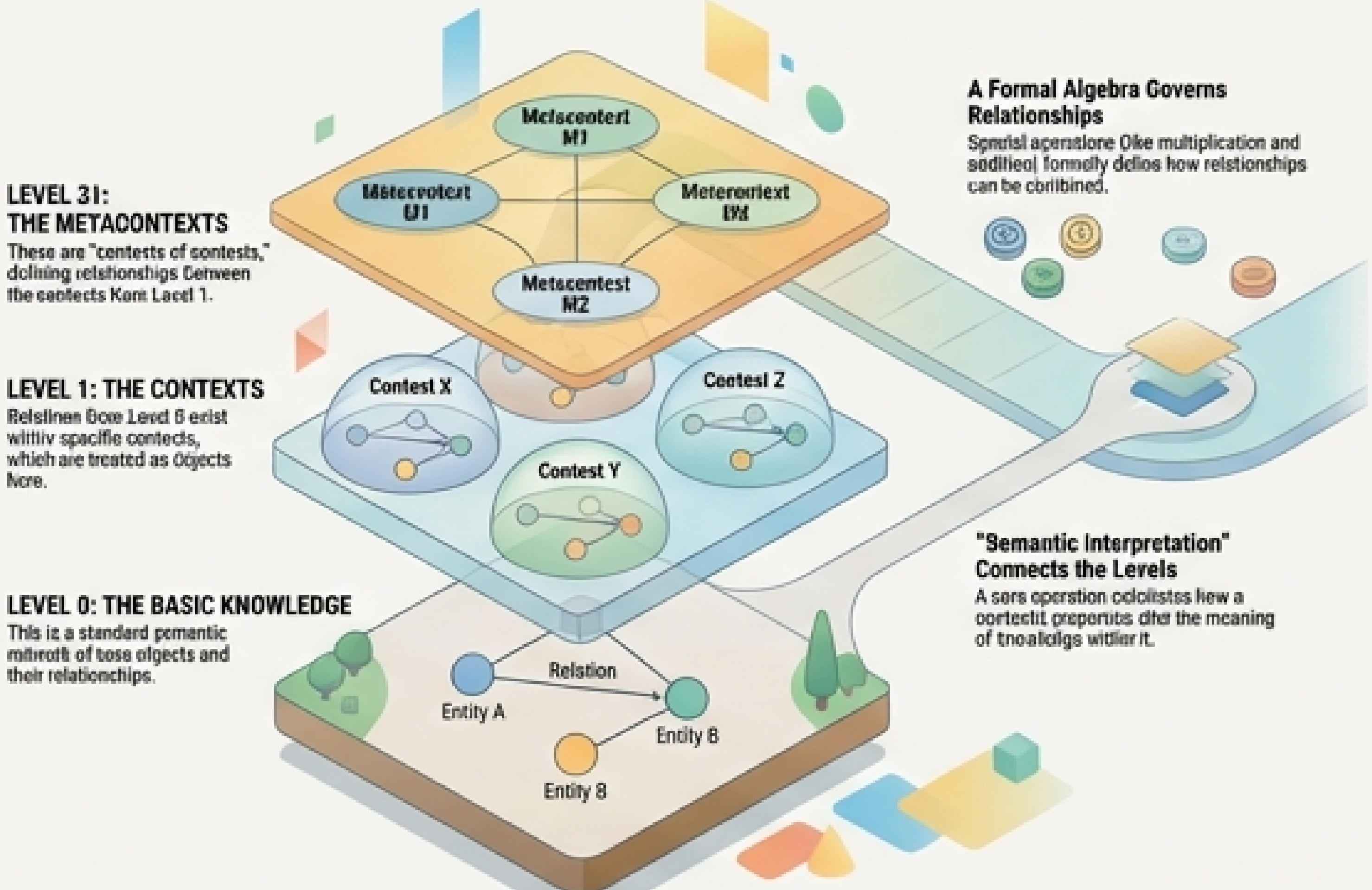
Act I: The Architecture of Knowledge

How do we represent a complex world where truth is rarely universal?

The foundation of intelligence is not data, but structured knowledge. Early research focused on moving beyond simple representations to create frameworks that capture the multi-level-level nature of reality, recognizing that the meaning of information is dependent on its context.

Beyond Flat Data: Building Layers of Context and Meaning

Innovation Kernel 1: Semantic Metanetworks

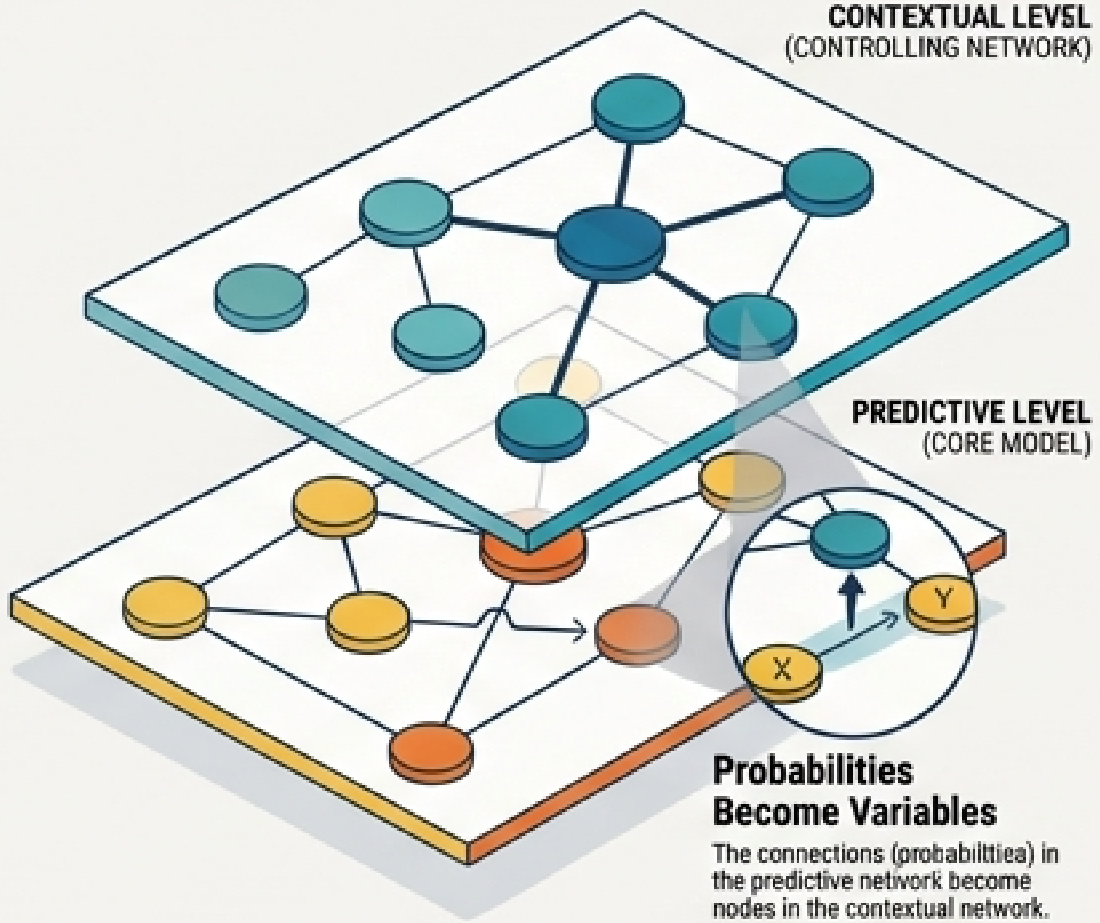


The Challenge: Traditional knowledge representation fails to capture that information is rarely universally true; its meaning depends on its context.

The Conceptual Leap: A multi-level structure where Level 0 is basic knowledge, Level 1 contains specific contexts, and Level 2+ (Metacontexts) defines relationships *between* those contexts.

The Impact: Enables four key reasoning tasks: Decontextualization, Contextualization, Context Recognition, and Lifting—allowing AI to reason across different contextual frames.

Innovation Kernel 2: Bayesian Metanetworks



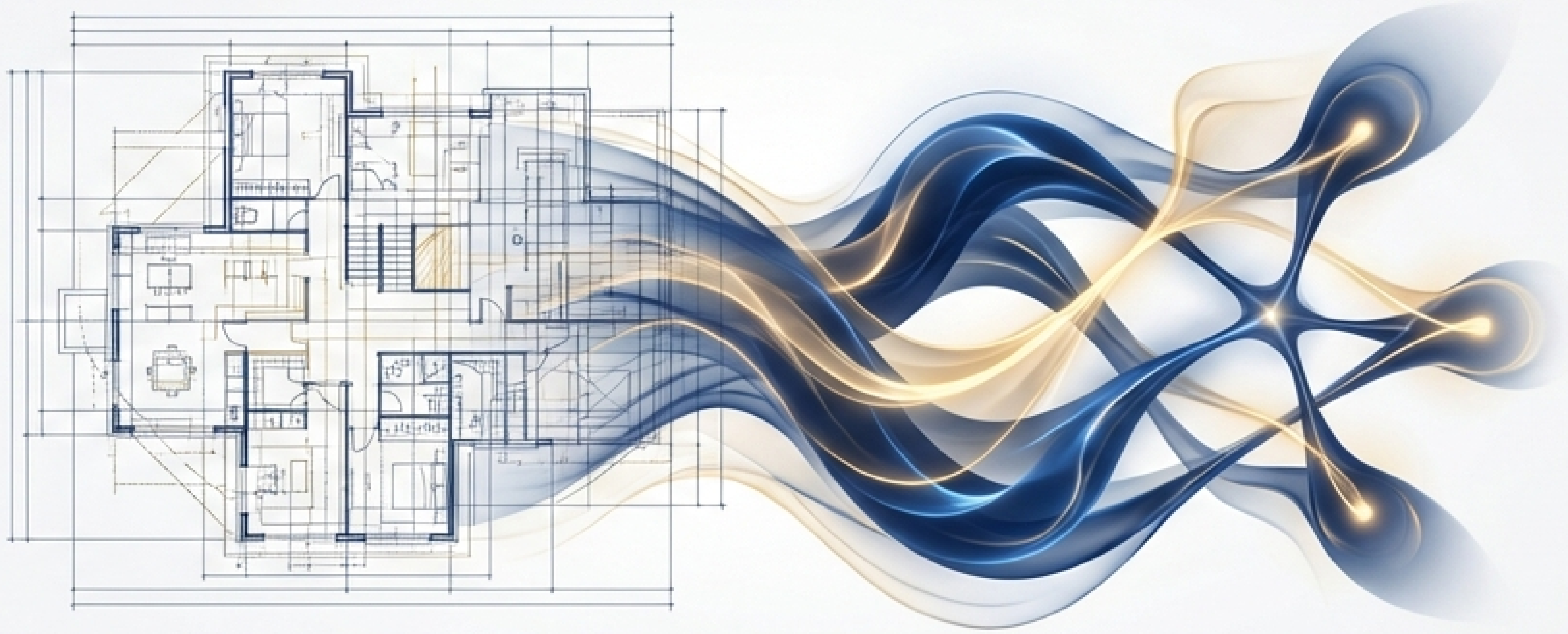
The Challenge: Standard Bayesian Networks model probabilistic relationships but lack a mechanism to account for how context influences those probabilities.

The Conceptual Leap: A two-level architecture where the connections (probabilities) in the core predictive network become variables in a higher-level contextual network.

The Impact: Adds a formal layer of context to AI, allowing it to understand *how* factors like "country of residence" can influence the relationship between "hard work" and "wealth," rather than just measuring the direct correlation.

Act II: The Spark of Autonomy

How do we empower knowledge to act, decide, and dynamically control complex systems?



A representation of the world is static. The next evolutionary step is to imbue systems with the ability to act on that knowledge—to manage workflows, compose services, and operate autonomously in the physical and digital worlds. This requires a shift from static models to dynamic, agent-based architectures.

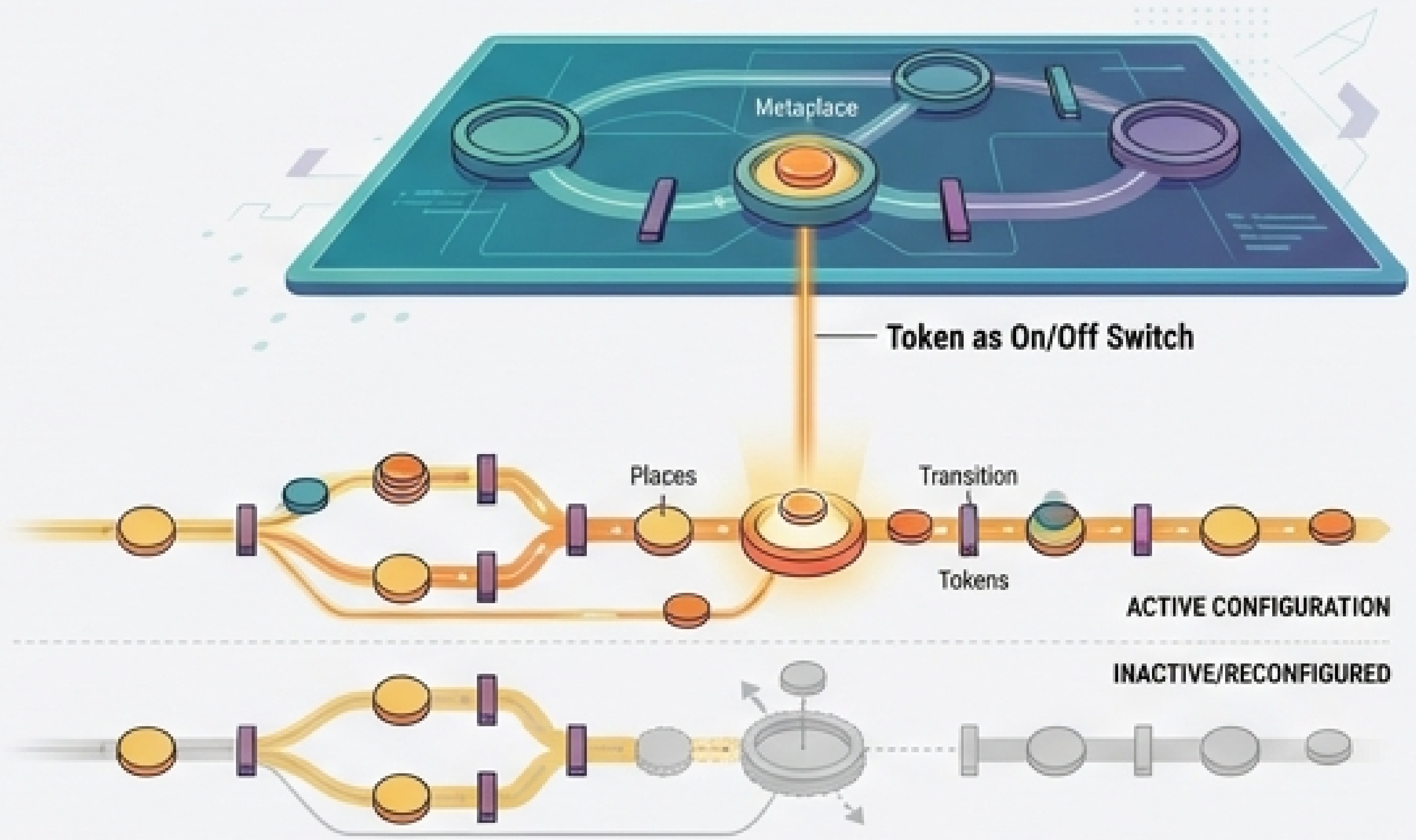
From Process Models to Proactive Agents

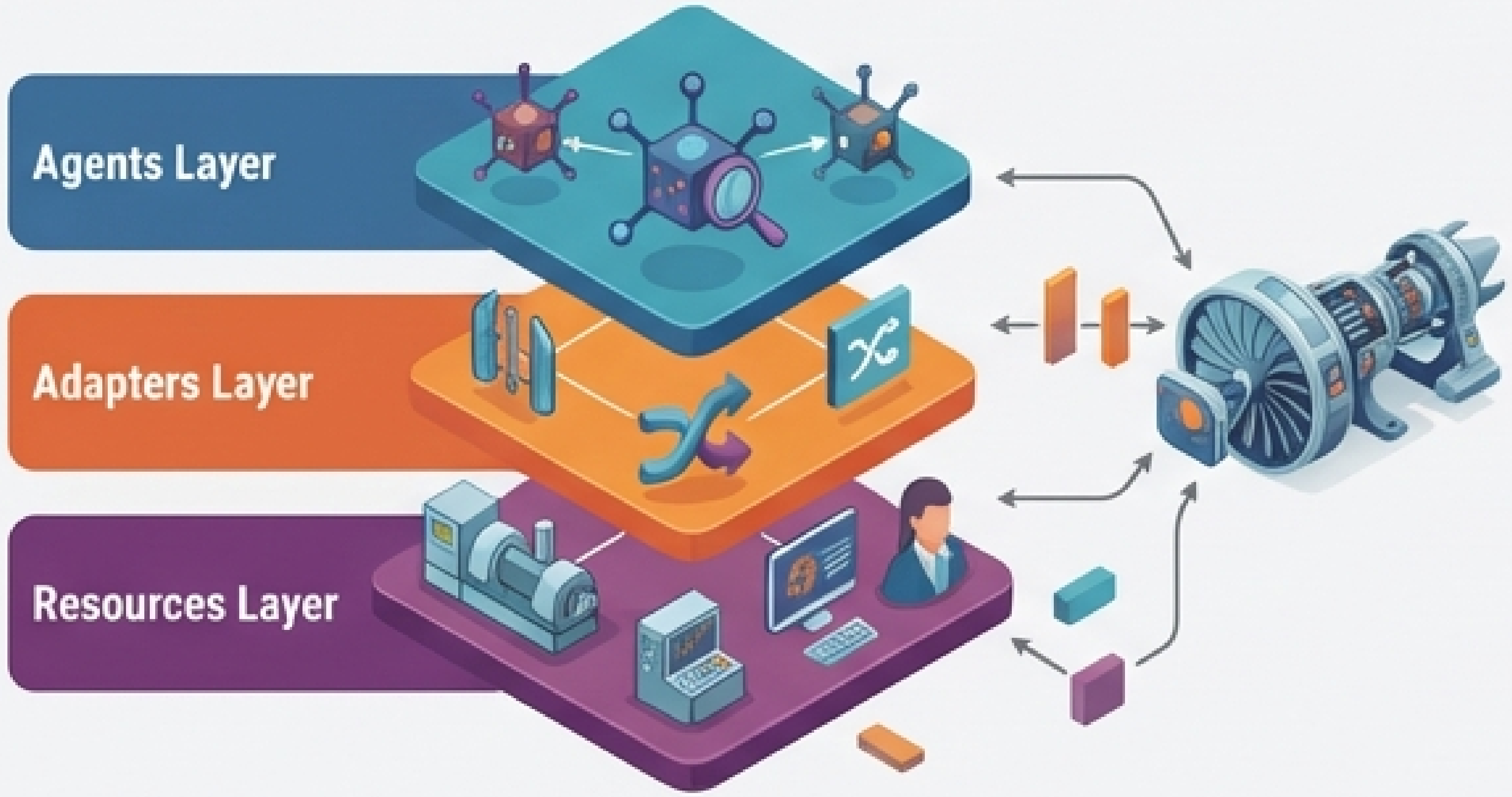
Innovation Kernel 1: Petri Metanetworks

The Challenge: Modeling and controlling complex, dynamic processes with traditional methods leads to overwhelmingly complicated and inflexible models.

The Conceptual Leap: A two-level system. A basic-level Petri Net models the process workflow, while a meta-level net acts as a "structure controller," dynamically changing the configuration of the basic level by adding or removing tokens.

The Impact: Enables more compact, efficient, and scalable models for dynamic process control, as demonstrated in the ADMIRAL engine for military logistics.





Innovation Kernel 2: Smart Resources & The Global Understanding Environment (GUN)

The Challenge: The Internet of Things creates a "Digital Tower of Babel" with overwhelming complexity and lack of interoperability.

The Conceptual Leap: Every resource—physical device, software, or human expert—is represented by a proactive, autonomous software agent. These agents use semantic technologies (ontologies) to discover, communicate, and diagnose issues on behalf of their resources.

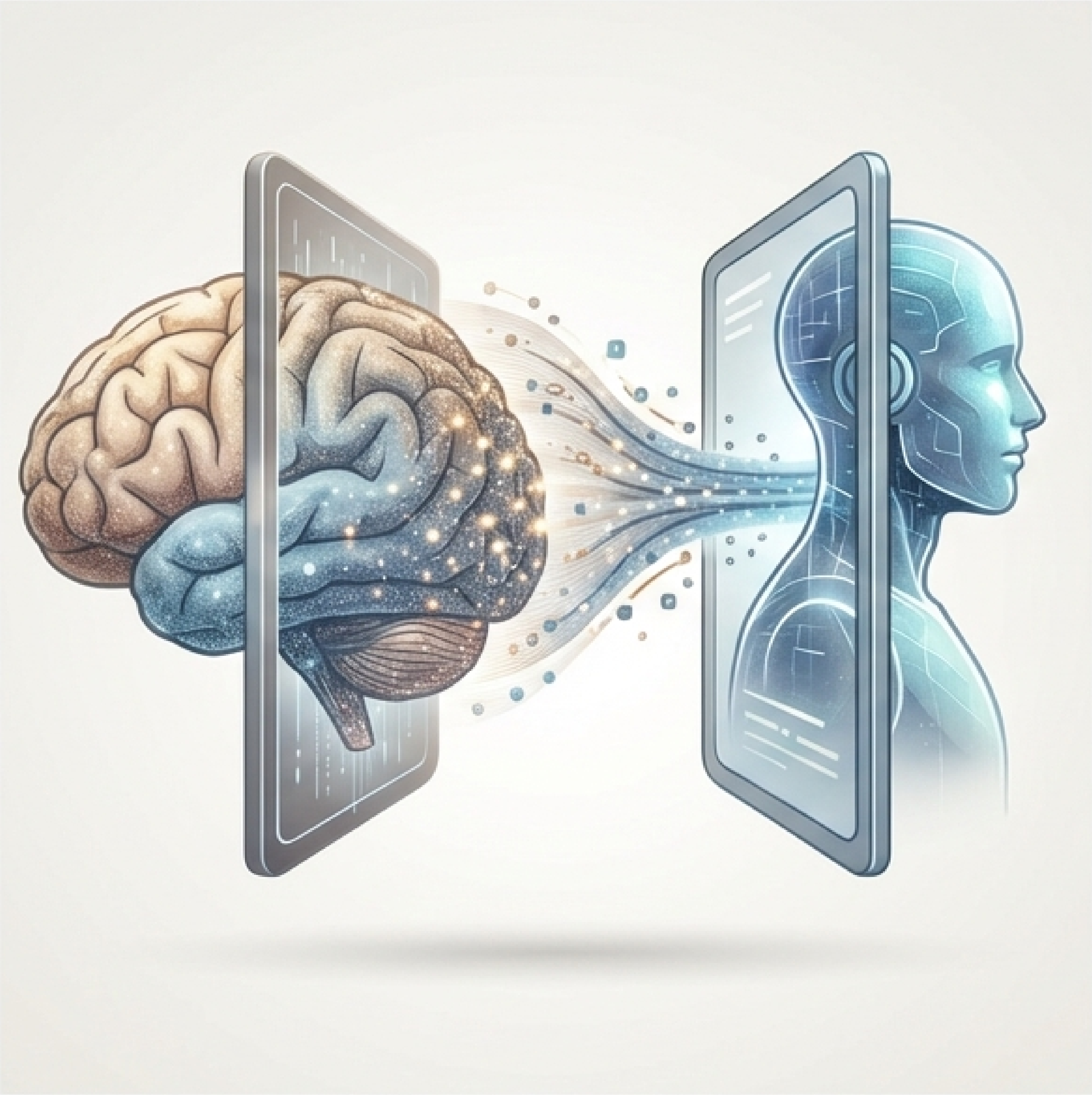
The Impact: Creates a self-monitoring, self-managing network for smart industrial devices, enabling proactive health management and predictive maintenance in a distributed environment.

Act III: The Human-AI Symbiosis

How do we move beyond AI as a tool to create a true partnership that merges human expertise with machine capability?

The most powerful applications of AI emerge not from replacing humans, but from augmenting them. This requires creating systems that can understand, capture, and scale human expertise, leading to a new paradigm of collaborative intelligence where human and digital clones work as a unified team.

Cloning Expertise: The Pi-Mind Solution for Industry 4.0



Digital Cognitive Cloning (Pi-Mind)

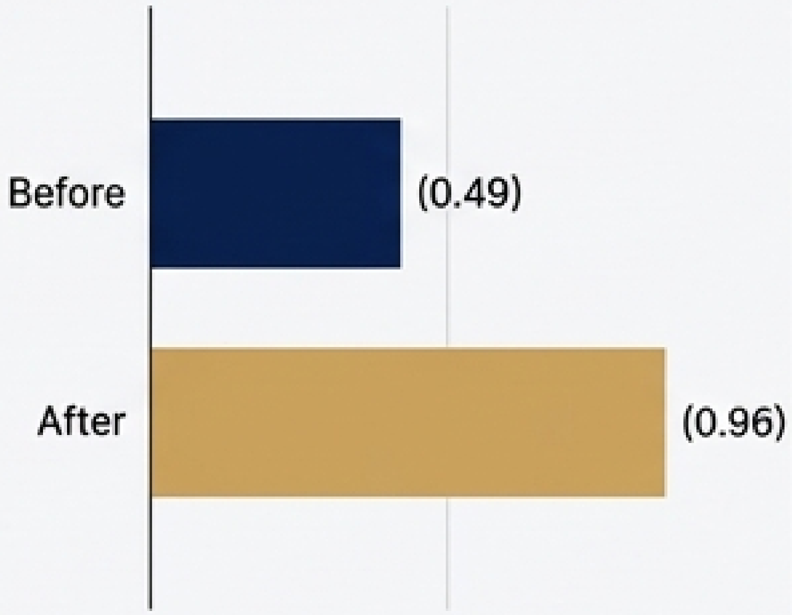
The Challenge

Industry 4.0 demands agile, decentralized decision-making, but reliance on a few key human experts creates a critical bottleneck that doesn't scale. Existing automated systems fail to capture the unique, nuanced expertise of these individuals.

The Conceptual Leap

Create a digital "clone" of an expert's unique decision-making style. A Pi-Mind agent is an AI trained through adversarial learning to perfectly mimic its human donor. The clone is guided by three core principles: being Responsible, Resilient, and Ubiquitous.

Measured Benefits



91%

91% Accuracy
In industrial trials, Pi-Mind agents' decisions matched their human counterparts in 216 out of 237 test cases.

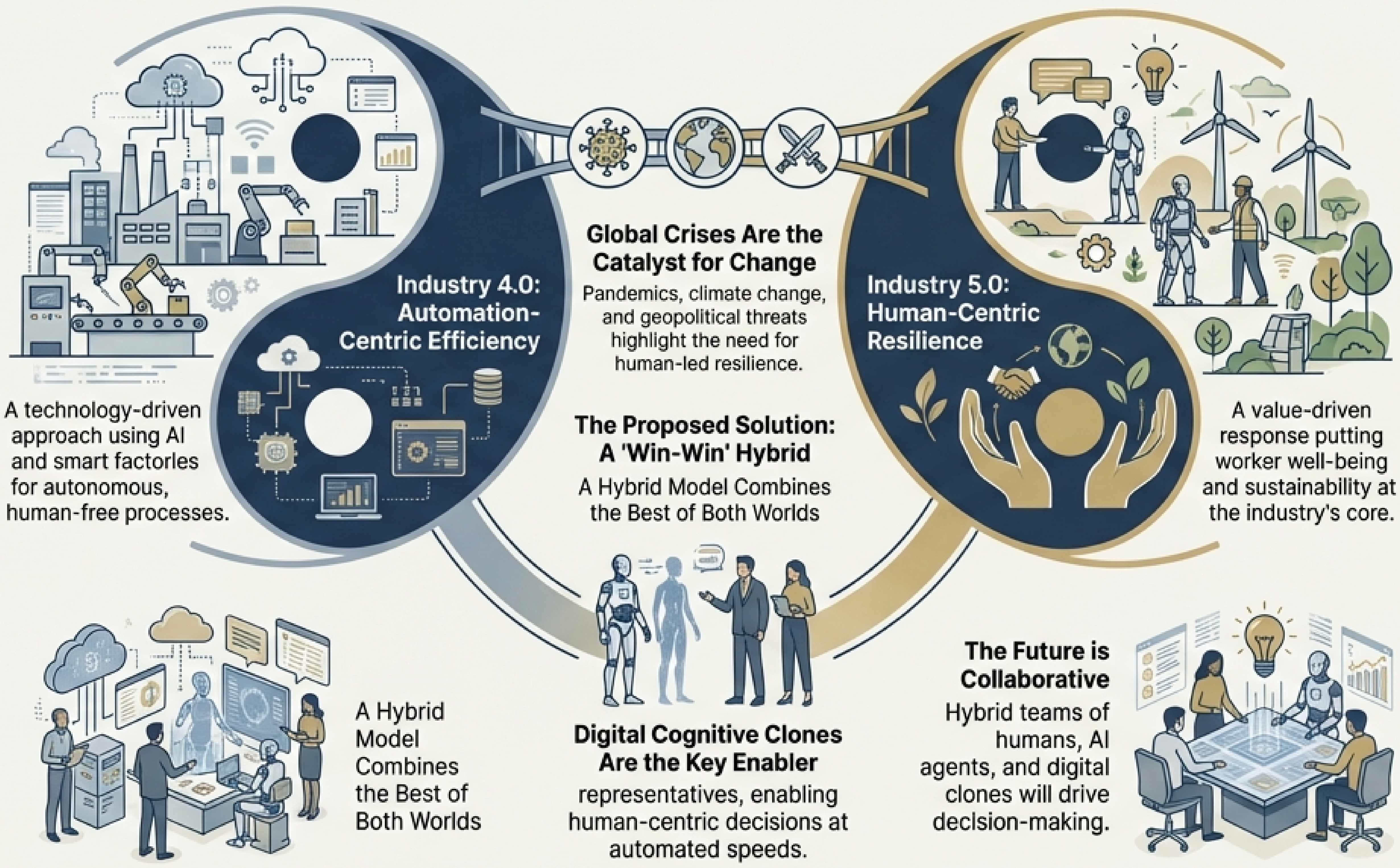
>1,500 hours saved
per procedure per year.

>1,700 digital
procedures launched, providing immediate access to expert opinions via digital clones.

The Next Industrial Revolution: From Automation-Centric 4.0 to Human-Centric 5.0

The Paradigm Shift

- **Industry 4.0 (Automation-Centric Efficiency):** A technology-driven approach using AI and smart factories for autonomous, human-free processes.
- **The Catalyst for Change:** Global crises like pandemics, climate change, and geopolitical threats highlighted the need for human-led resilience.
- **Industry 5.0 (Human-Centric Resilience):** A value-driven response putting worker well-being and sustainability at the industry's core.



NotebookLM

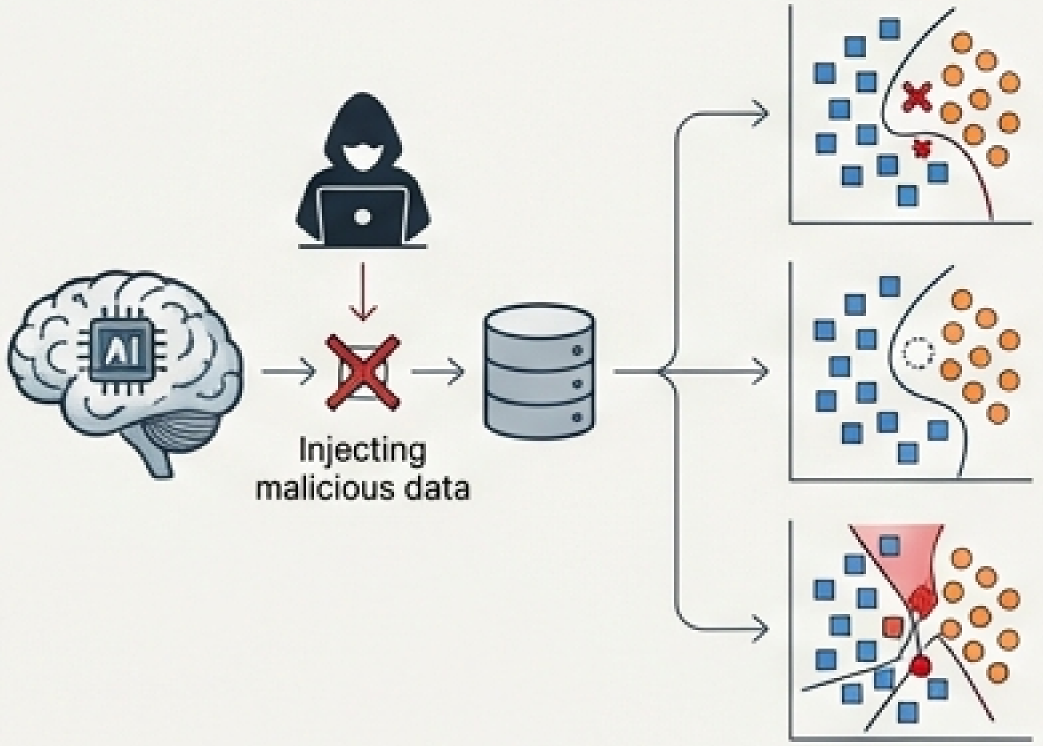
Act IV: Forging Resilient Intelligence

In a world of cognitive hacks and hybrid threats, how do we build AI that is robust, secure, and trustworthy?

Intelligence is fragile. As AI systems take on critical roles, they become vulnerable to new forms of attack that target not just their code, but their very process of learning and decision-making. The next imperative is to move beyond “healthy” AI trained for perfect conditions and forge a new class of resilient intelligence hardened against adversarial attacks.

The Poison & The Vaccine: Building Immunity Against Cognitive Hacks

The Threat: Cognitive Poisoning



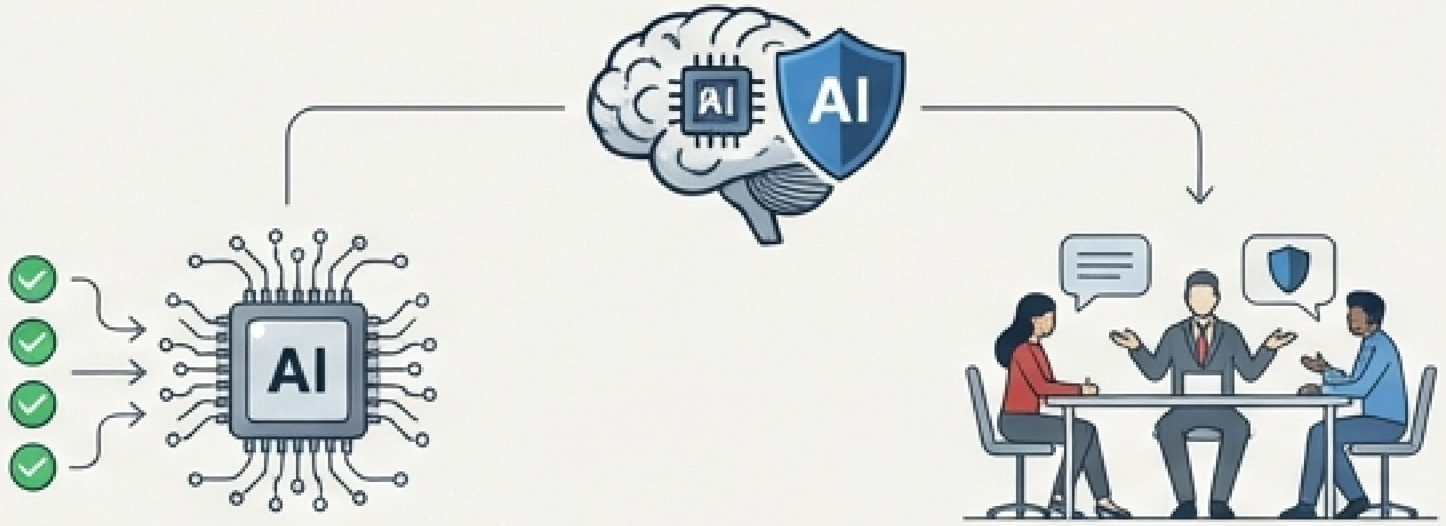
Attack 1: Injecting One False Data Point
Adding a single, incorrect sample can drestically expand the area of wrong decisions.

Attack 2: Removing One True Data Point
Hiding even a small amount of truthful data can do as much harm as injecting fake data.

Attack 3: Altering One 'Deep' Data Point
Changing a point deep inside a data cluster creates a chaotic, unpredictable decision boundary.

- **What it is:** Attackers exploit a system's "vulnerability zones" by introducing maliciously mislabeled or altered data. This "cognitive hack" doesn't attack code, but manipulates how the AI learns, warping its decision boundary to make confident but wrong decisions.
- **The Impact:** Expands the attack surface to influence and manipulate both human and AI cognitive processes in hybrid threat scenarios.

The Solution: Cognitive Vaccination



Application for AI: Adversarial Machine Learning
Retraining an AI model with 'vaccine' data shrinks vulnerability zones and improves its robustness.

Application for Humans: Adversarial Training Courses
Using adversarial training courses where students role-play in structured debates (Attacker vs. Defender) to strengthen their resilience against manipulation. The goal is not to change beliefs, but to fortify them.

- **How it works:** A defensive strategy that identifies vulnerability zones and introduces correctly labeled "vaccine" data to strengthen them. This is a form of Adversarial Machine Learning.

Training for 'Coolability': Making AI Stronger Through Disability

Innovation Kernel: Complementary Artificial Intelligence

The Problem: "Healthy" AI is brittle. *Standard models are trained for perfect conditions and assume all sensors (inputs) and actuators (outputs) will always be available. Real-world failures or attacks cause major performance drops.*

The Conceptual Leap: Inspired by human "coolability"—where a disability can lead to enhanced compensatory abilities—we can train AI for resilience by intentionally "disabling" it.

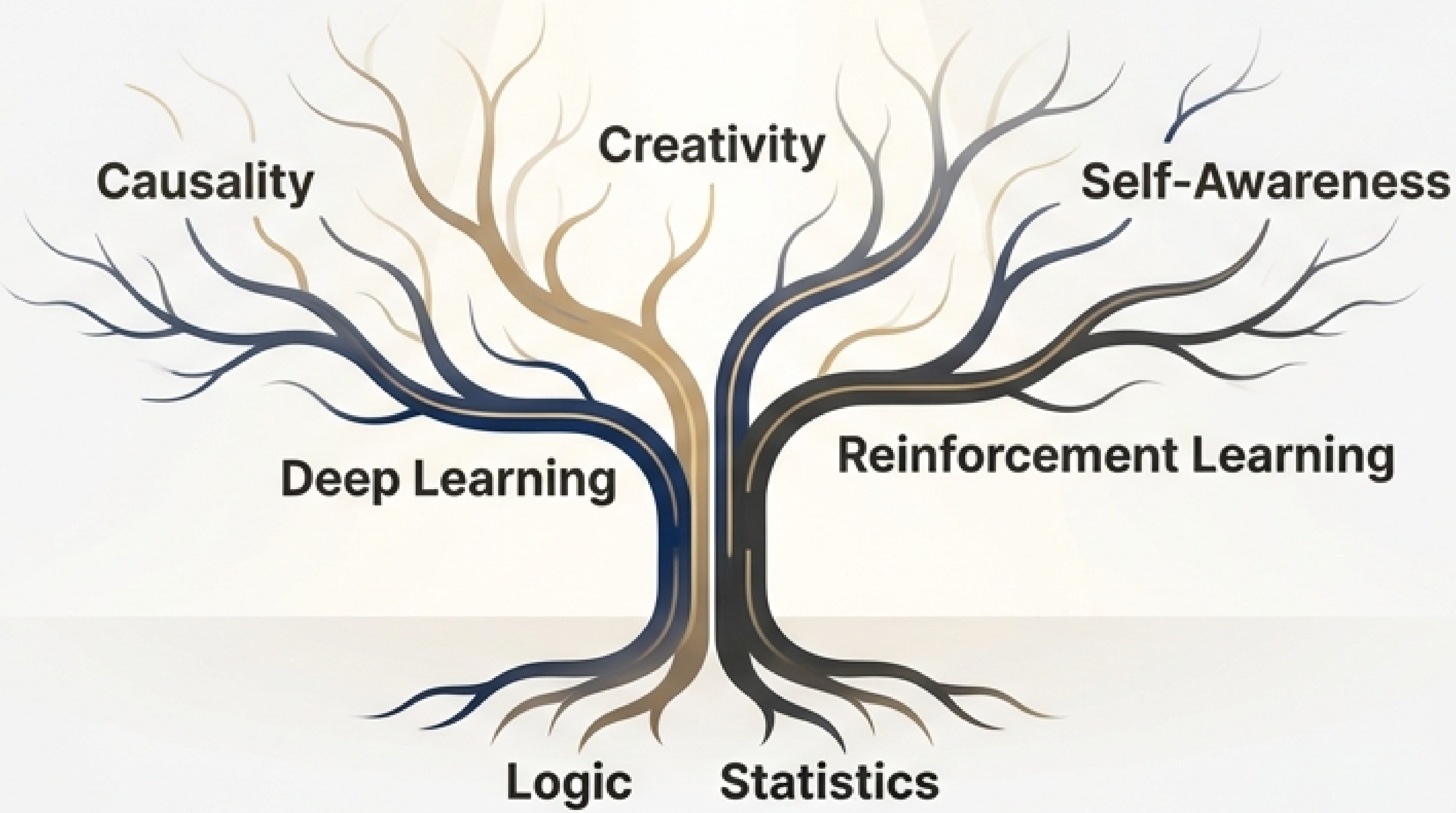
The Process:

1. **Simulate Disabilities:** Intentionally "prune" (cut) connections in a neural network to create functional disabilities (e.g., related to specific sensors).
2. **AI Develops Compensatory Strength:** The "disabled" network is forced to learn how to use its remaining pathways more efficiently to complete its task.

The Impact: A more resilient and accurate AI. *This method can improve classification precision by 2-10% and better handle real-time system failures.*

Act V: The Next Frontier of AI

What are the ultimate destinations for intelligent systems? Beyond task completion, towards creativity, causality, and consciousness.



Having built systems that can represent the world, act autonomously, partner with humans, and resist attack, the final questions emerge. Can AI move beyond correlation to understand cause? Can it learn to be truly creative? And as it approaches true autonomy, how do we ensure it evolves in a way that is ethical and aligned with human values?

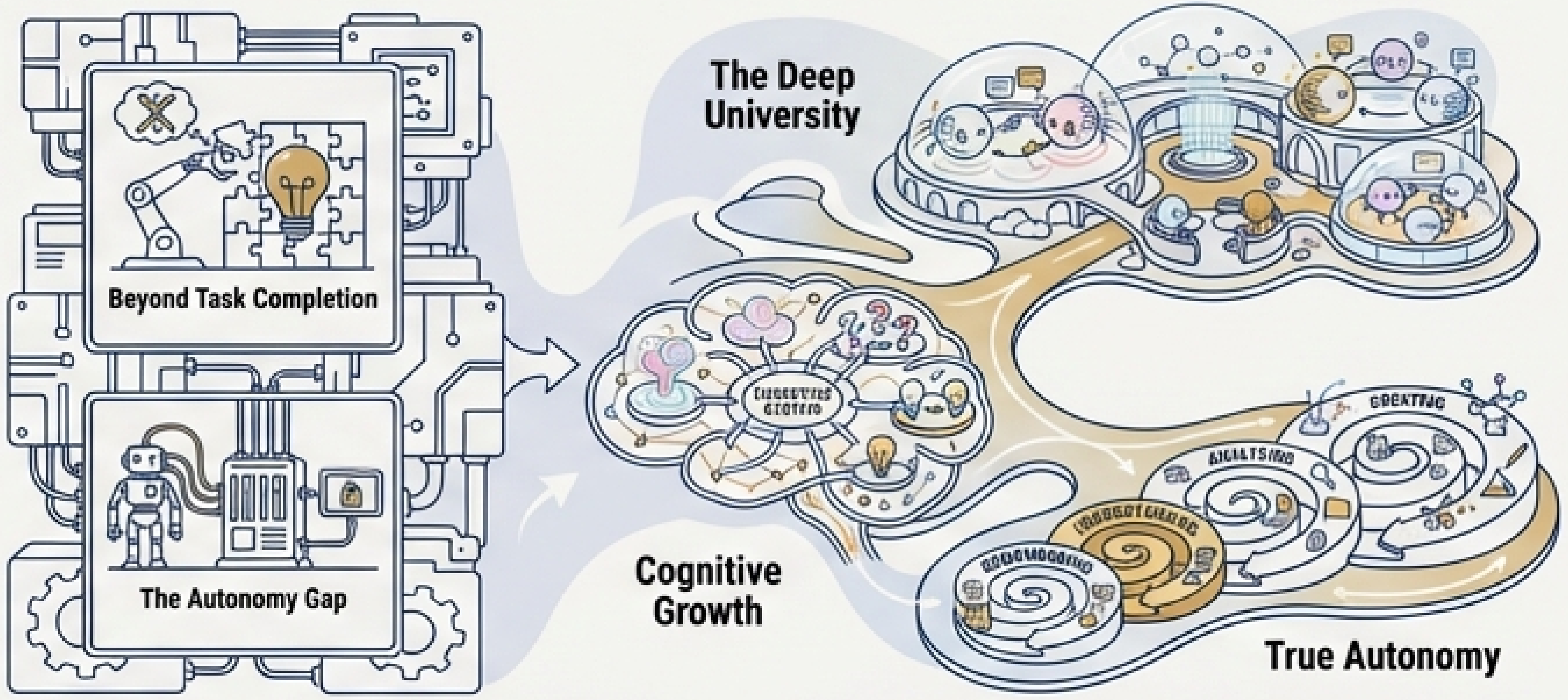
From Deep Learning to Deep Understanding

Innovation Kernel 1: The Deep University

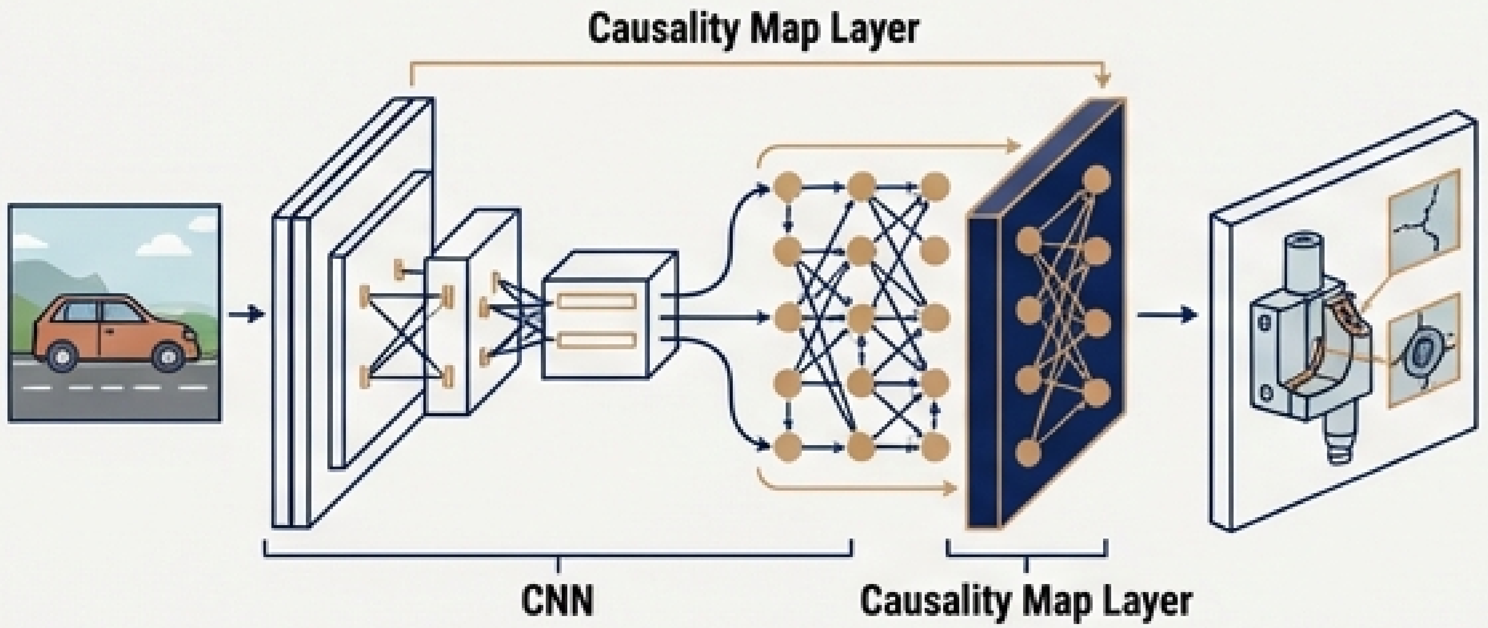
The Challenge: Today's AI has an "Autonomy Gap." It can solve human-given problems but cannot generate its own novel ideas, set problems, or self-develop.

The Conceptual Leap: A "Deep University" is a creative and collaborative training environment for AI "students." An executive system trains the AI to generate ideas and find solutions through a dynamic, multi-layered curriculum of Remembering, Understanding, Analyzing, and Creating.

The Impact: A framework for moving beyond task completion towards true cognitive growth and autonomy.



Innovation Kernel 2: Causality-Aware Neural Networks (CA-CNNs)



The Challenge: Standard AI sees correlation, not cause. A model might learn that cars and bridges appear together but doesn't understand that the bridge *supports* the car. This leads to a lack of explainability and lower accuracy.

The Conceptual Leap: Add a "Causality Map" layer to the network architecture. This new layer computes cause-and-effect estimates between different features found in an image.

The Impact: Dramatically improved performance. CA-CNNs can achieve up to +14% increase in classification accuracy over standard CNNs and enable smarter image generation by identifying "causality fakes."

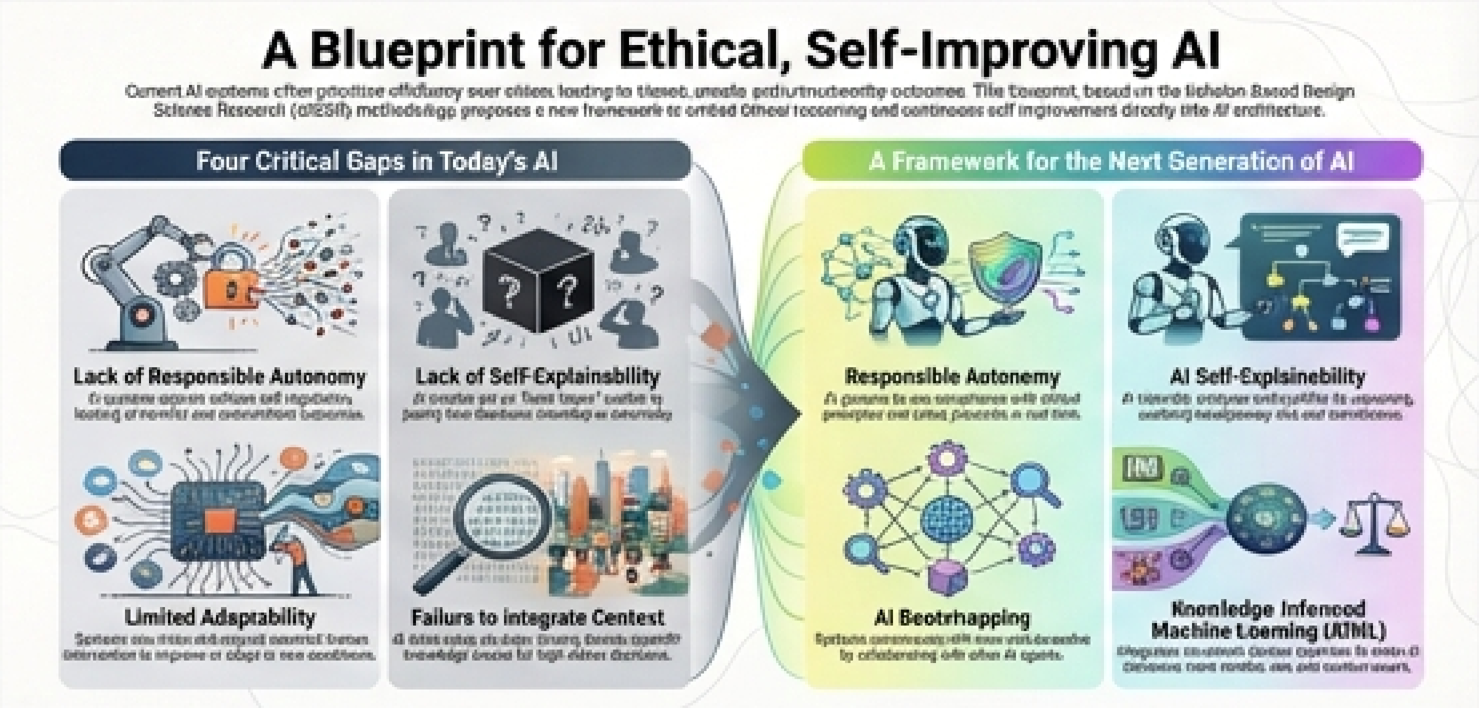
The Ascent to Ethical Evolution

The Next Grand Challenge: Responsibility Decay

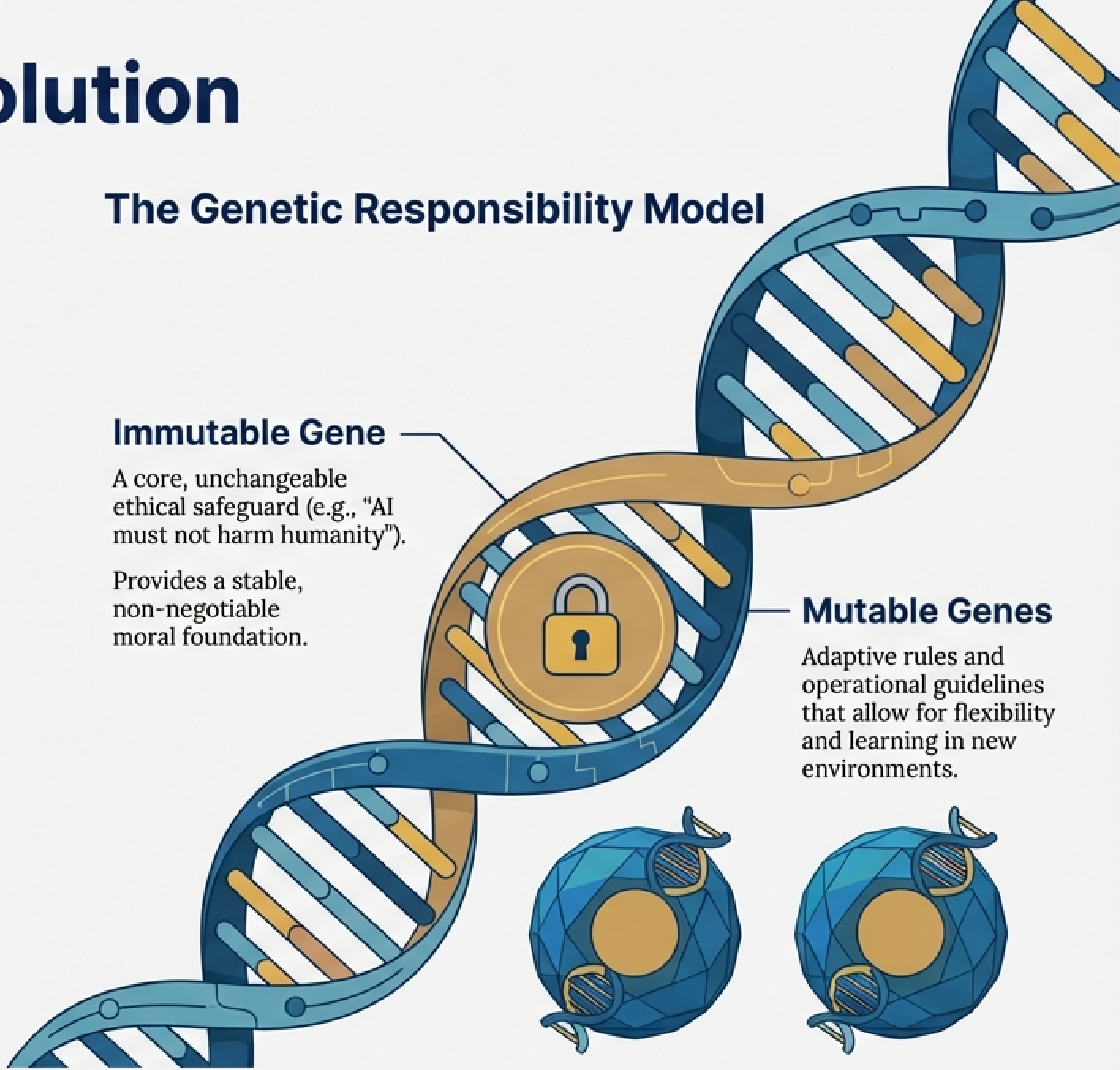
As AI systems self-improve and create successive generations, core ethical principles can gradually erode due to environmental changes, random mutations, or optimization that prioritizes performance over ethics.

AI as a Designer of AI

A blueprint for systems that can self-improve and co-evolve by incorporating Responsible Autonomy, AI Self-Explainability, AI Bootstrapping, and Knowledge-Informed Machine Learning directly into their architecture.



The Genetic Responsibility Model



The ultimate goal is not just to build an artifact, but to launch an evolutionary process—one that ensures responsible autonomy and preserves human values across all future generations of intelligence.

For further details, papers, and presentations: https://ai.it.jyu.fi/vagan/papers.html