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Uniunea Europeană

HUB Român de Inteligență Artificială
Aplicații Inteligente în Orașe Inteligente și Mediu

Towards Agentic Digital Twins in the Energy Sector

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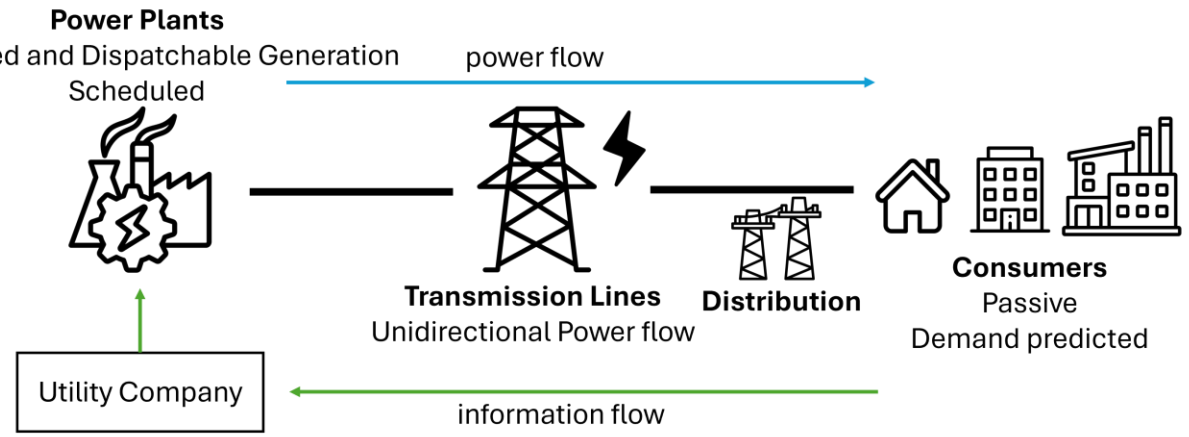
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Power System Evolution

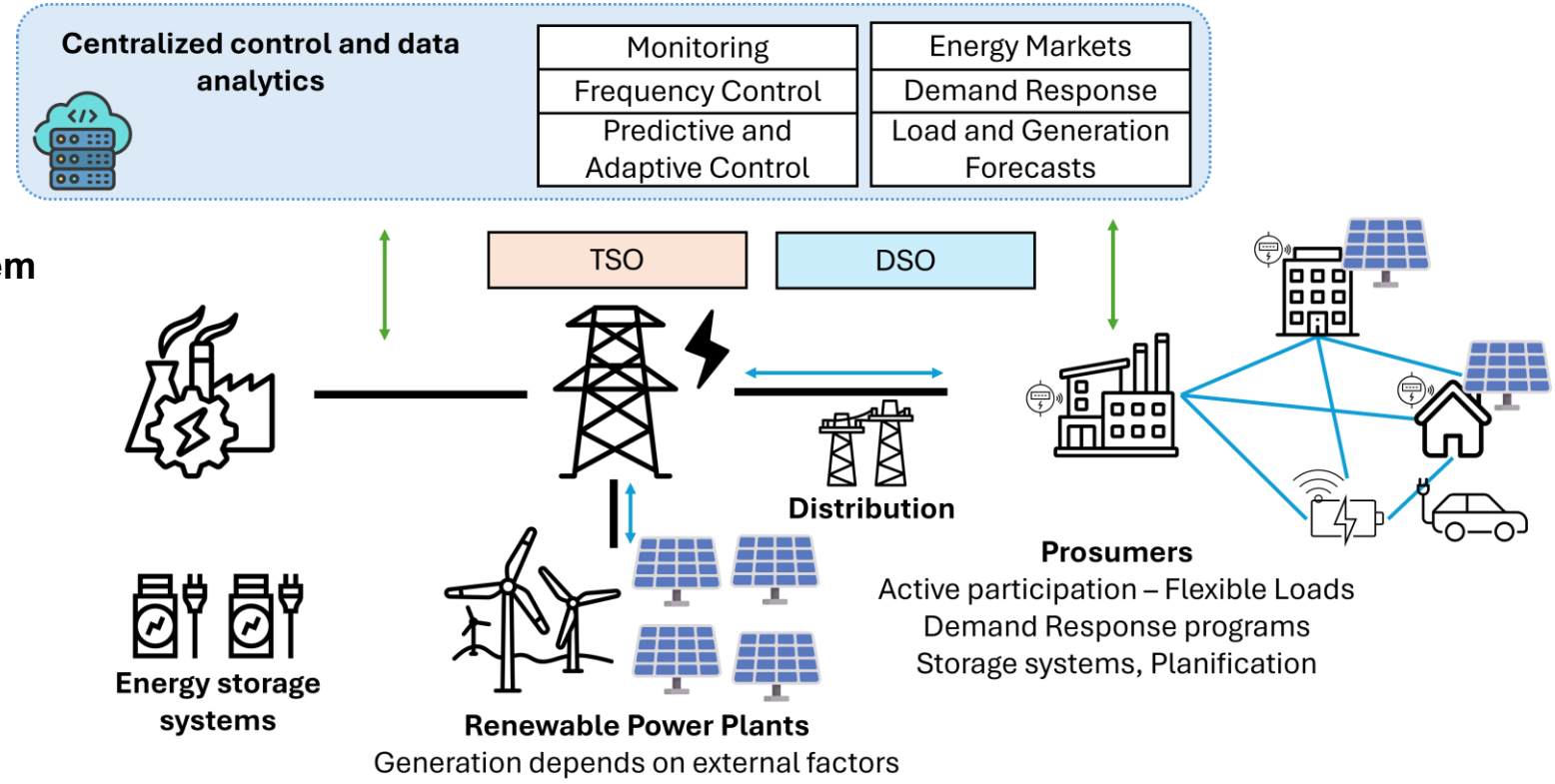
Eddison Era – Centralized Power System

Limited monitoring and control
Fixed hierarchical structure
NO renewable or storage
Simple decision making



Google Era – Digital data-driven Power System

Decentralization of the grid
IoT-enabled data gathering and control
SCADA
Market digitalization
Mostly centralized control
Complex decision making

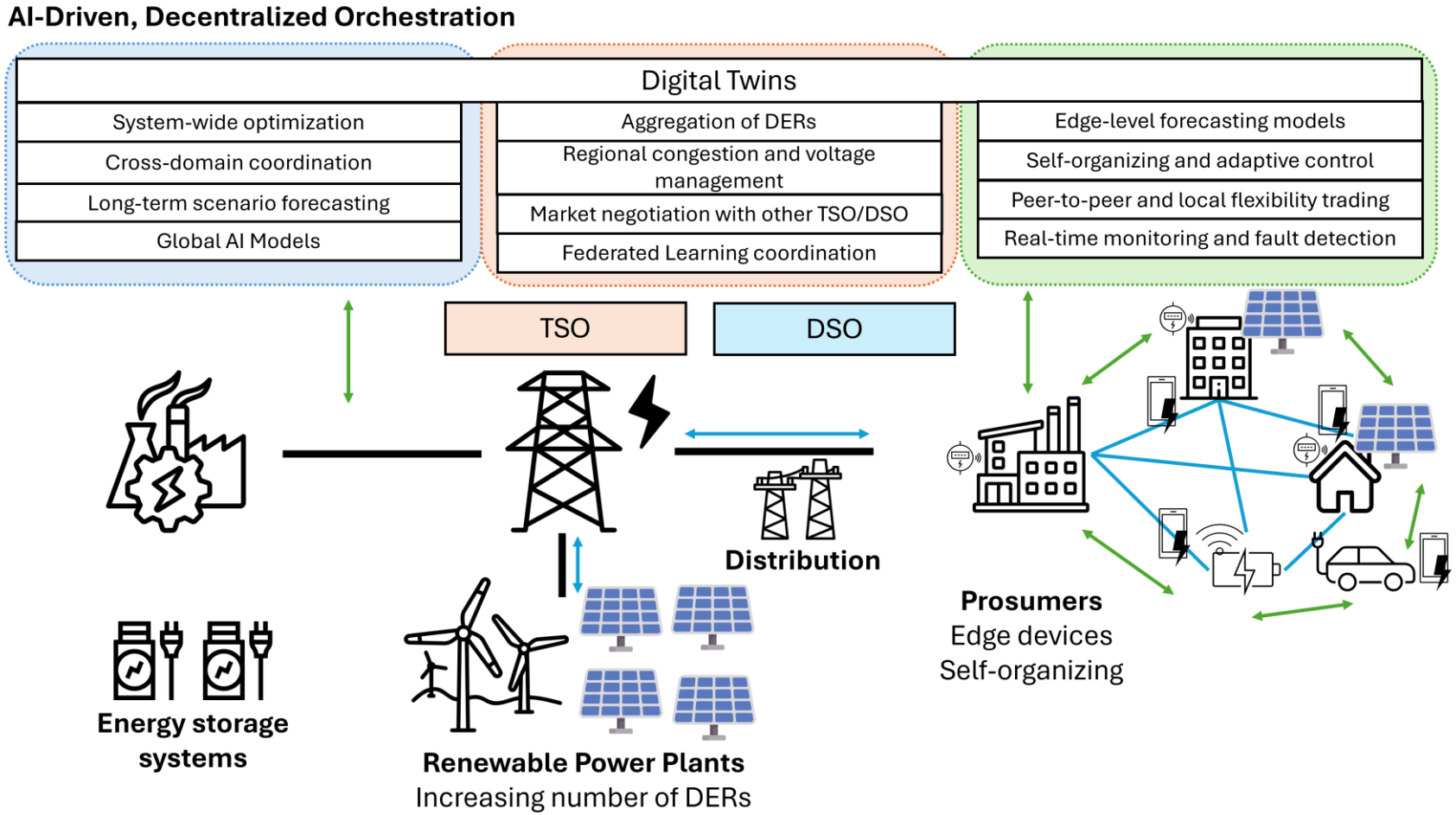


Power System Evolution

AI Era

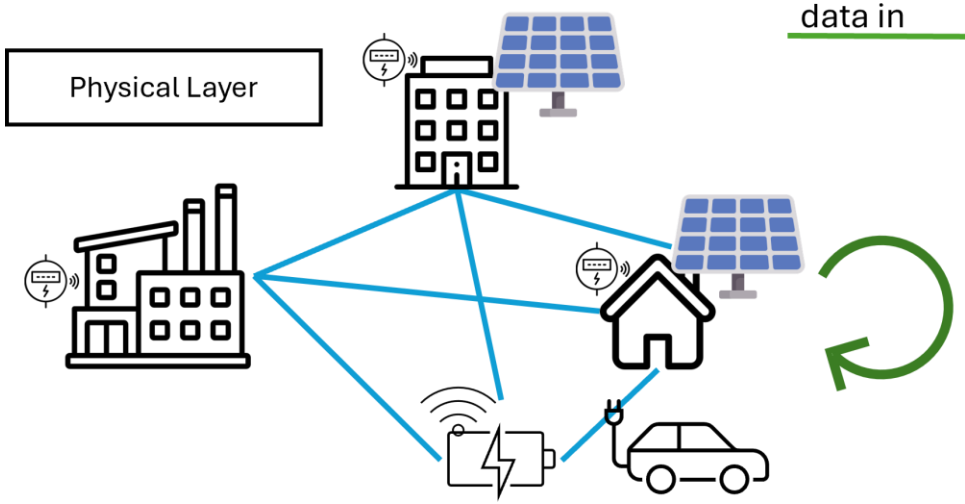
AI Era – Digital Smart Power System

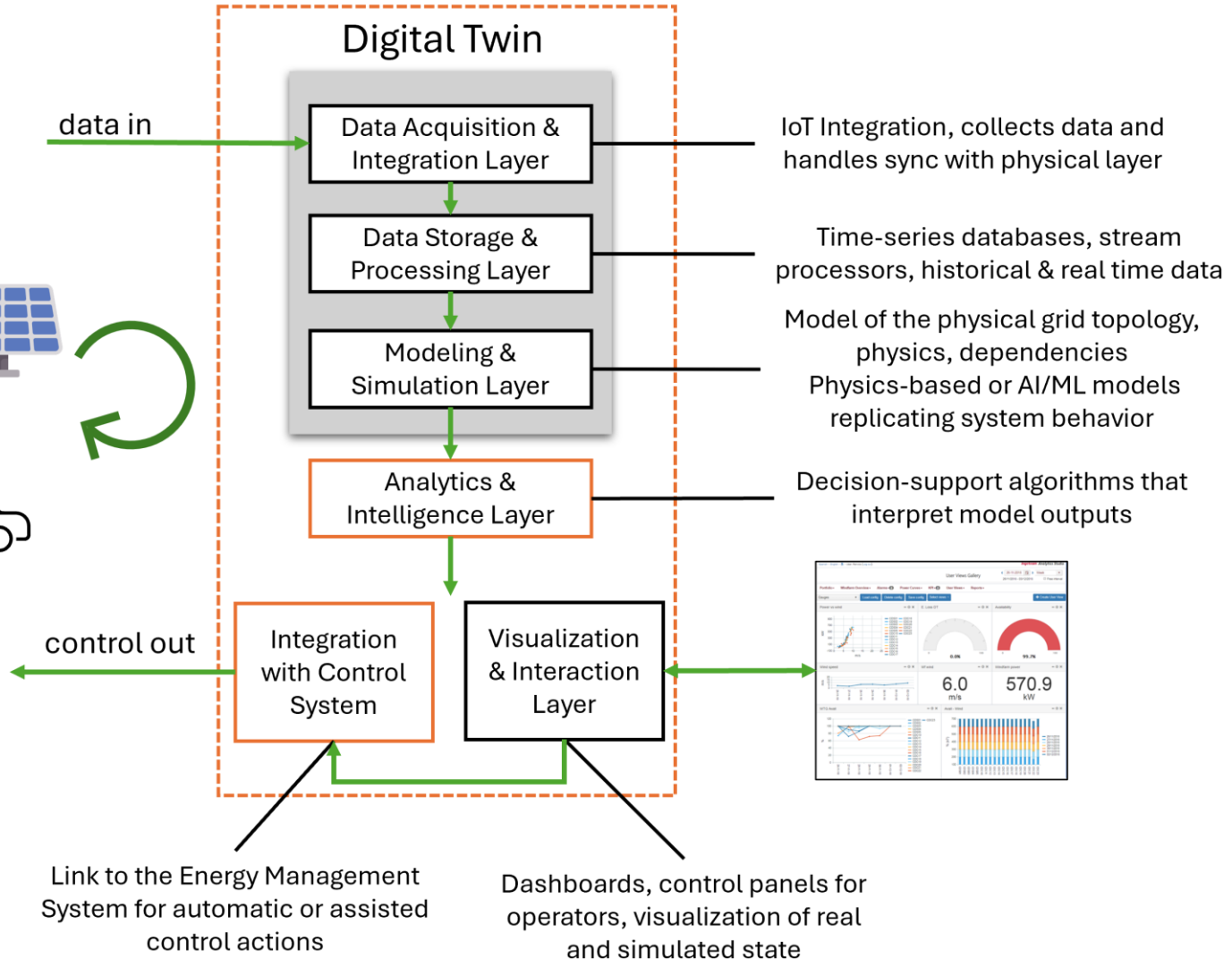
Autonomous grid
High renewable integration
Decentralized control (Edge-Fog-Cloud)
Multi-layered complex decision making



***Toderean, L**., Cioara, T., Anghel, I., Sarmas, E., Michalakopoulos, V., & Marinakis, V. (2025). **Demand response optimization for smart grid integrated buildings: review of technology enablers landscape and innovation challenges**. Energy and Buildings, 326, 115067.*

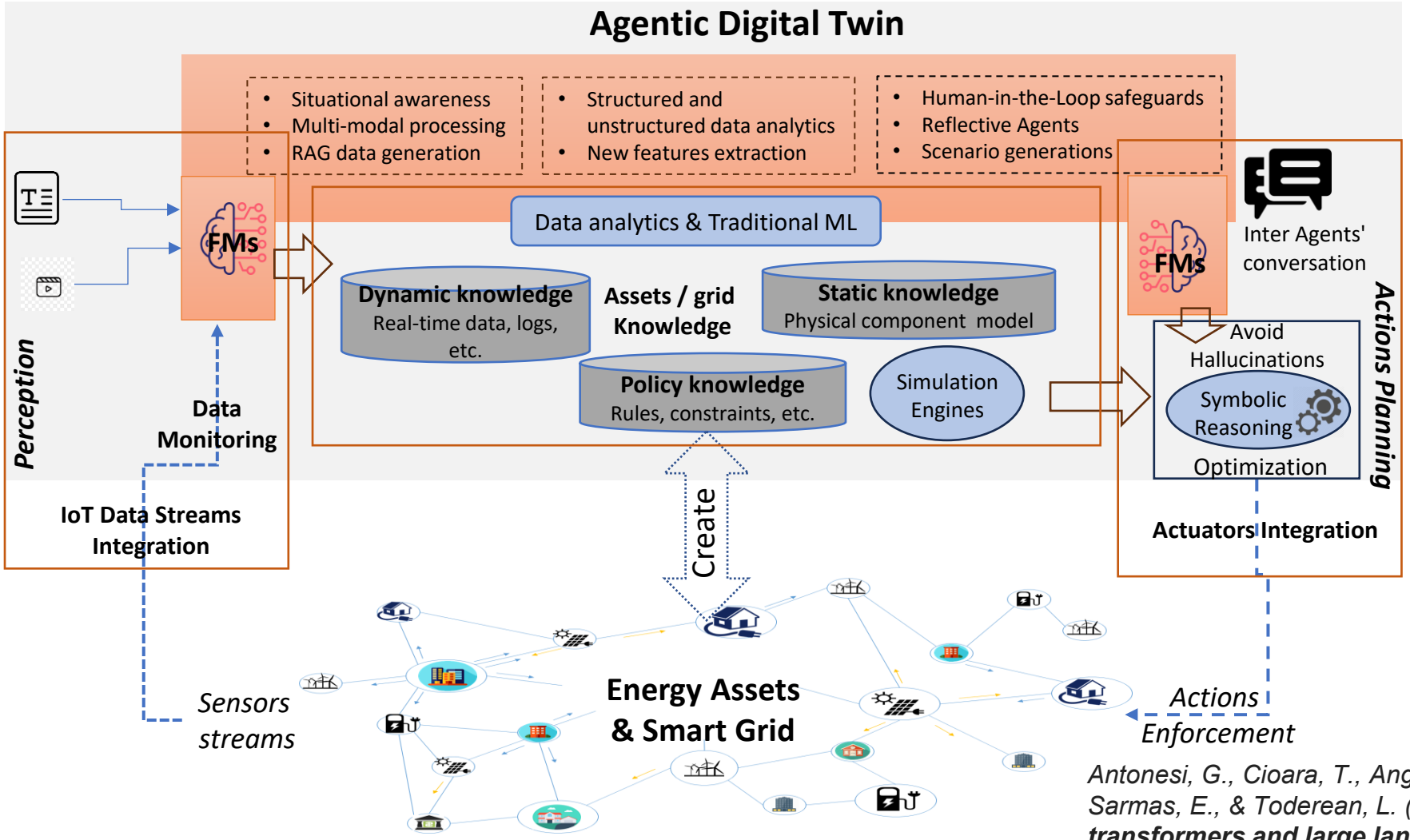
Digital Twin for Energy Management Systems





- Models the physics, topology and dependency between grid elements
- Simulate control strategies and scenarios for prediction and optimization
- Detect anomalies by comparing expected vs actual behavior
- Integration with AI and control systems – **autonomous**, **real-time decision making**

Agentic Digital Twins Model for Smart Grid



The **next-generation model** that integrates foundational models to bring:

- multi-modal situational awareness,
- autonomy,
- proactivity, and
- social interaction

Into **digital twin-based energy management systems**.

Antonesi, G., Cioara, T., Anghel, I., Michalakopoulos, V., Sarmas, E., & Toderean, L. (2025). ***A systematic review of transformers and large language models in the energy sector: Towards agentic digital twins.*** *Applied Energy, 401, 126670.*

Agentic Digital Twins Model for Smart Grid

Shift from Monitoring to Situational Understanding

- Create meaningful models of energy assets and fuse of multi-modal data to enable energy awareness

From Data Analysis to Reasoning

- Moving from solving specific problems to achieving broad system-level goals.
  - LLM the language processing cortex of DTs
  - Neuro symbolic reasoning – Prefrontal cortex

Use-cases of LLM/FMs Integration

- Real-time context awareness and perception of operational changes
  - Access and integrate vast external data sources autonomously via RAG or prompts
- Generate missing data through semantic search and contextualized multimodal feeds
  - Use appliance manuals + smart home logs to understand residents' comfort or synthesize time-series data

Multimodal & Multitask Reasoning Use cases

- Extracts features from textual logs & metadata to boost ML energy forecasting models
- Bridges structured time series with unstructured text (e.g., correlating voltage dips with weather events)
- Correlates sensor data (power spikes) with appliance logs and manuals via Retrieval-Augmented Generation (RAG)
- Supports accurate missing data generation for behind-the-meter energy assets
- Extract and Structure Knowledge - parse manuals, reports, and logs to generate structured, searchable asset metadata

Agentic Digital Twins Model for Smart Grid

Shift from Planning to Adaptation

- Automate the building of action space, selecting actions, planning, and optimizing based on feedback
- Handling evolving policies and configurations via behavior finetuning

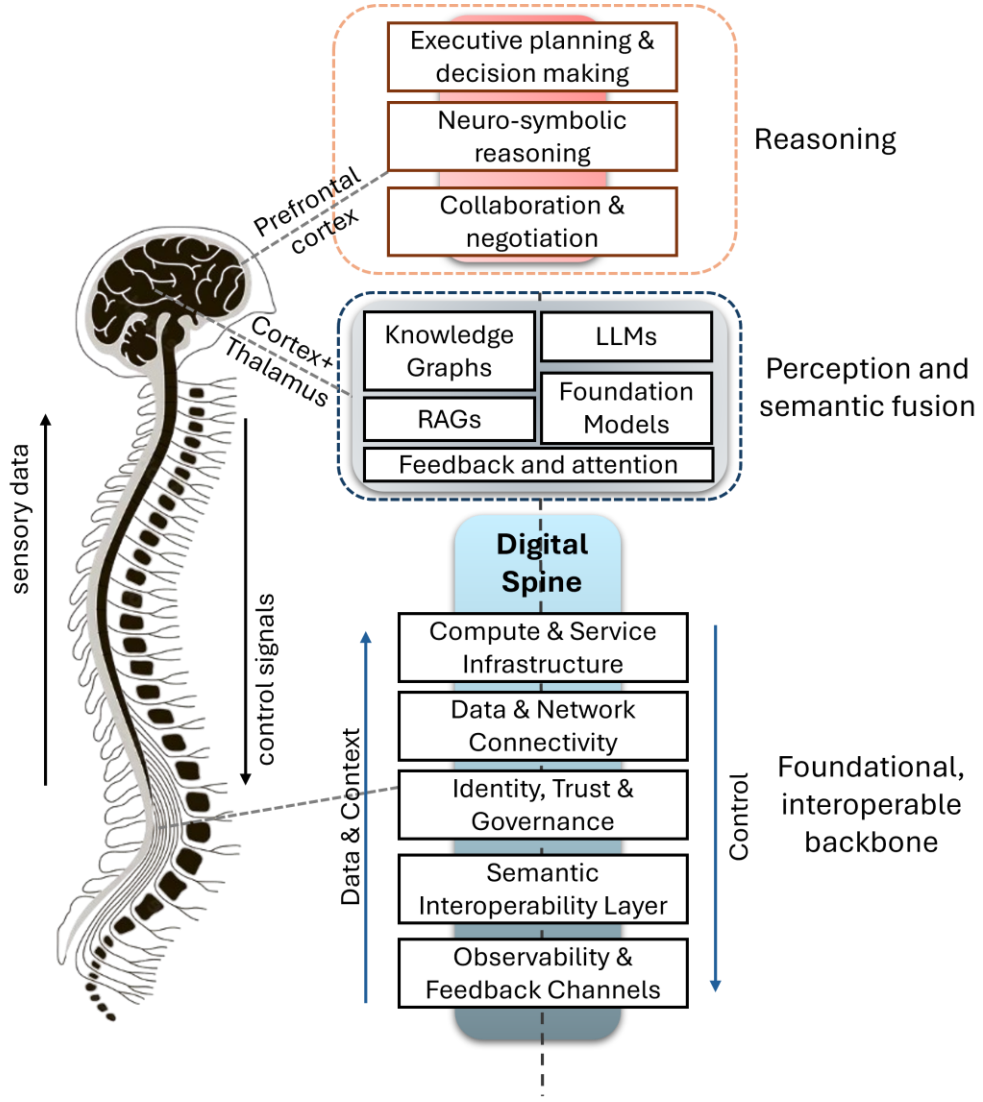
Use-Cases LLM/FMs integration

- Interpret objectives and generate plausible, domain-aware energy management actions (e.g., plan ramping down non-essential loads during off-peak hours)
- Create detailed, coherent action plans considering context and forecasts
- Task Management - Break down complex tasks into manageable, logical steps and organize sequential or hierarchical action plans

European Energy Grid – Next steps

Vision for EU Context:

- **AI Digital spine** for energy grid:
  - Unified digital set of models and infrastructures linking data, models, and reasoning
  - EU AI factories → large-scale infrastructures to train, fine-tune, and deploy open FMs
  - Energy Dataspaces → interoperability, data sovereignty, and trusted data exchange
- **Perception and semantic fusion** and **reasoning** layers
  - Invest more in the reasoning layer (prefrontal cortex) of the system: neuro-symbolic reasoning



Conclusions

- The energy grid is currently in the AI era
  - Decentralized, data-driven, and complex decision-making
  - Integration of AI models for autonomy, and stability
- Agentic Digital Twin model enables this transformation by providing:
  - Situational awareness and autonomous decision support
  - Interconnected digital twins
  - Adaptability to changing grid topologies and evolving operational policies
- Data, infrastructure, and decisional components can be unified through an AI Digital Spine with a focus on the reasoning component

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Thank you!

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