Tampere University

AI Agents in Smart Spaces

DigitAInability^{3D}

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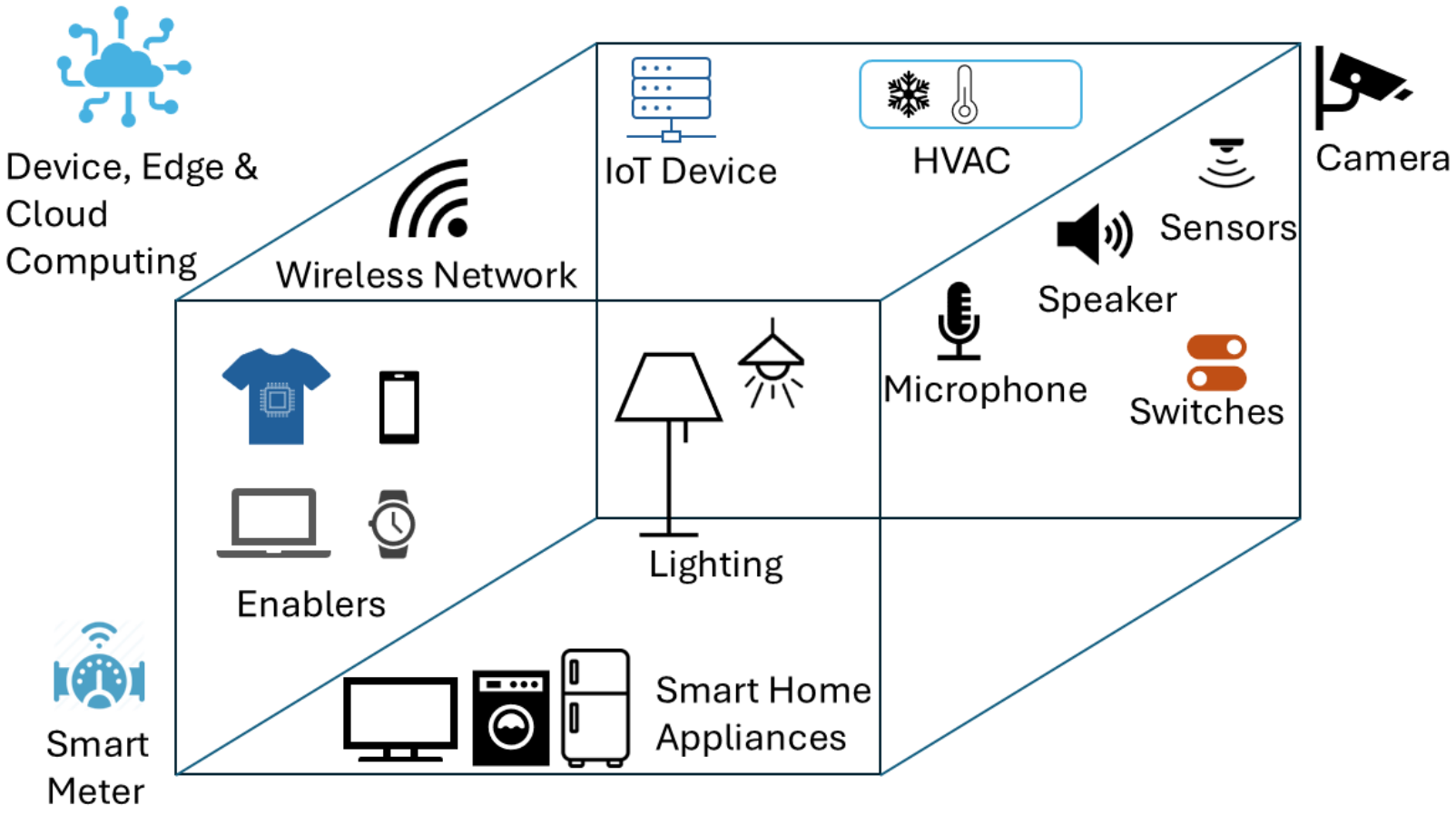
Outline

- What are smart spaces?
- Role of AI and their applications
- Challenges of utilizing AI
- AI agents
- What can go wrong?
- Prototype of local running AI agent

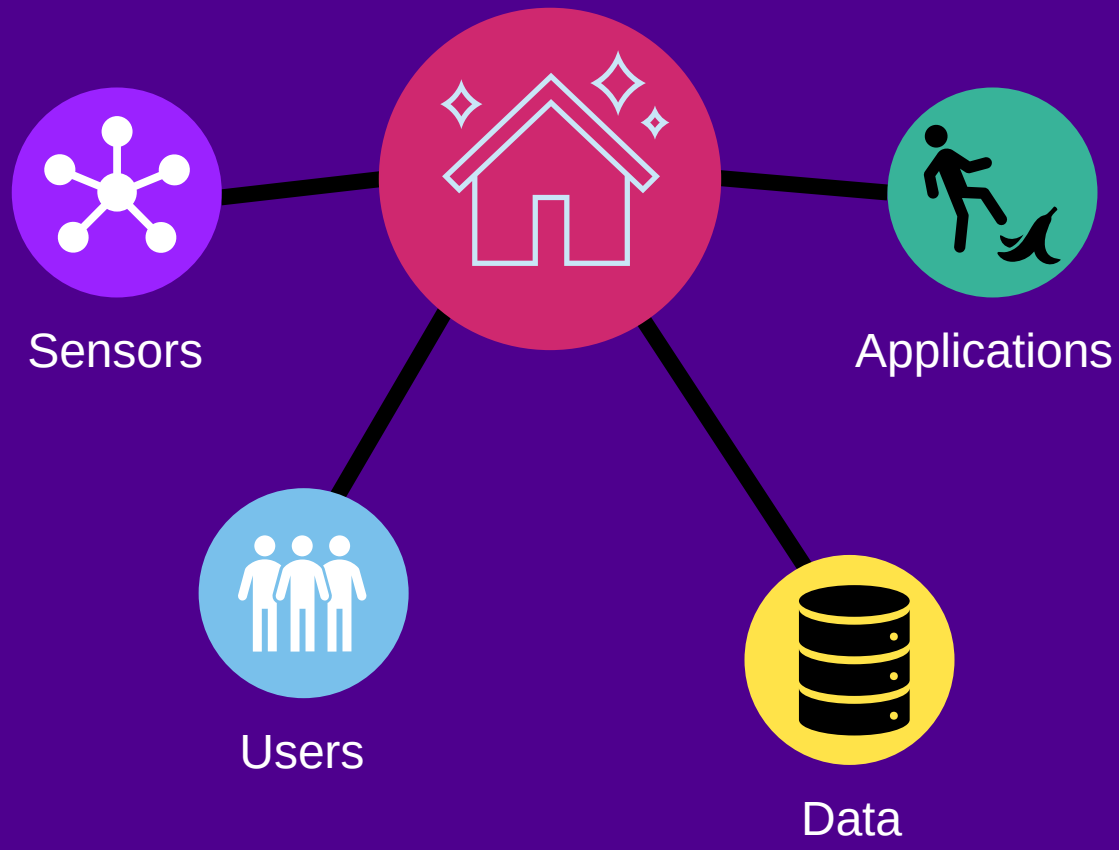
Smart Spaces



Smart Spaces

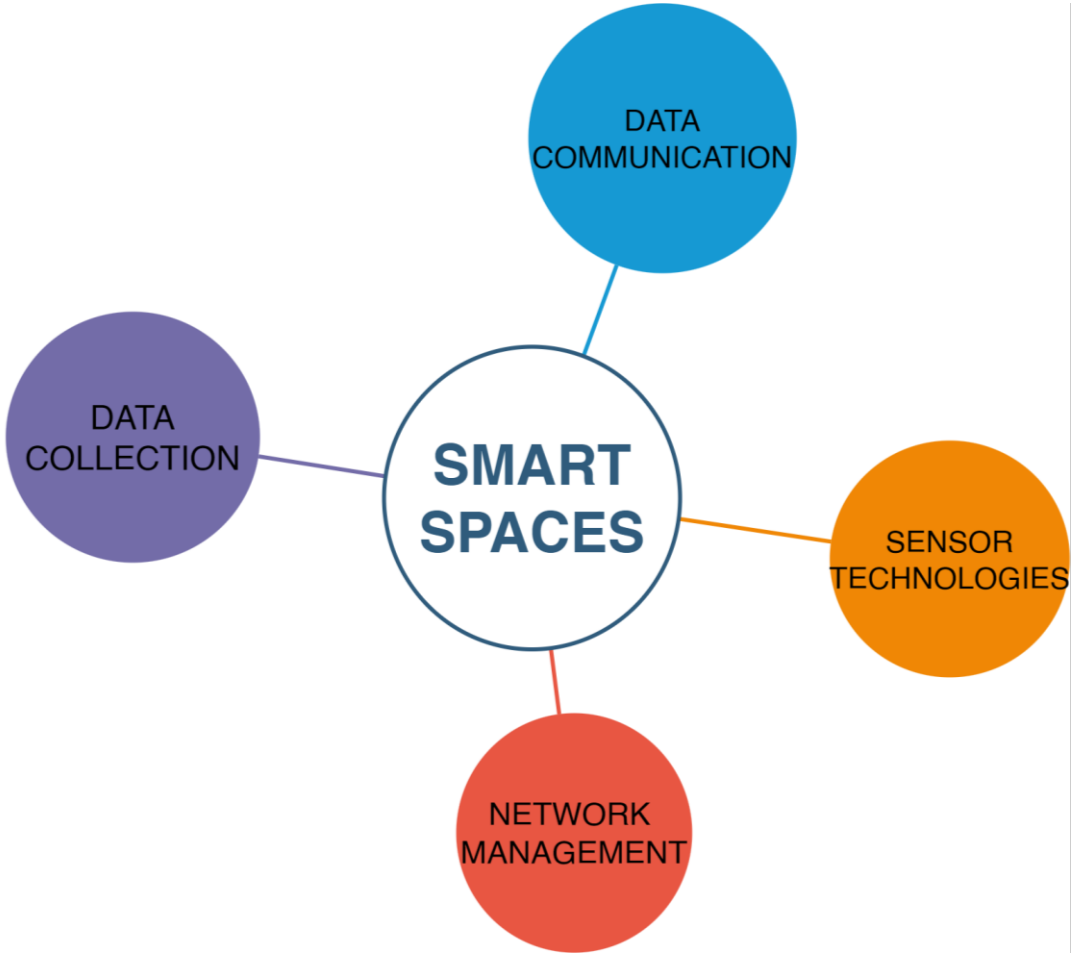
- Smart spaces are indoor environments equipped with computational capabilities and interconnected IoT devices such as sensors, actuators or machines
- They interpret sensory data to offer variety of applications to users

‘IoT enables objects to connect, communicate over the Internet’



Key Components

- Sensor technologies
- Data communication
- Network management
- Data collection and processing



Sensor Technologies

Environmental Sensors

Infrared Sensors

Cameras

Data Communication

Wireless Communication Technologies

WPAN
RFID
NFC
BLE
Zigbee

100m

WLAN
Wi-Fi

1km

WWAN
EC-GSM-IoT
NB-IoT
LTE-M

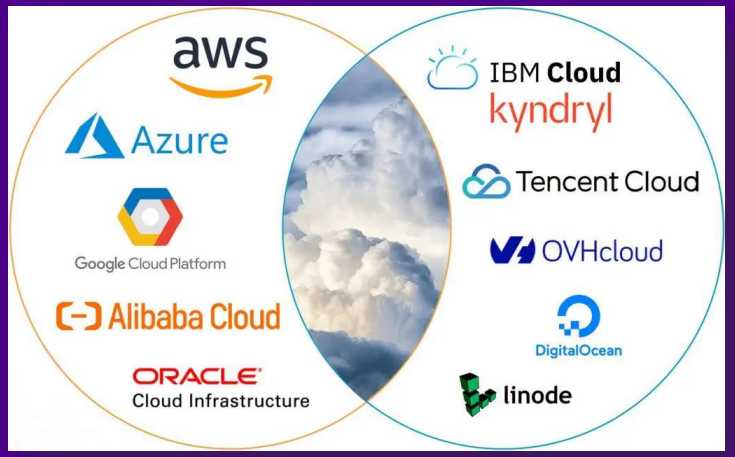
Network Management

- Energy management is important for the deployment of battery powered sensors

Data Collection and Processing

- Sensors generate data with different volumes, variations, and velacities
- Applications often require real-time data processing

Cloud Computing



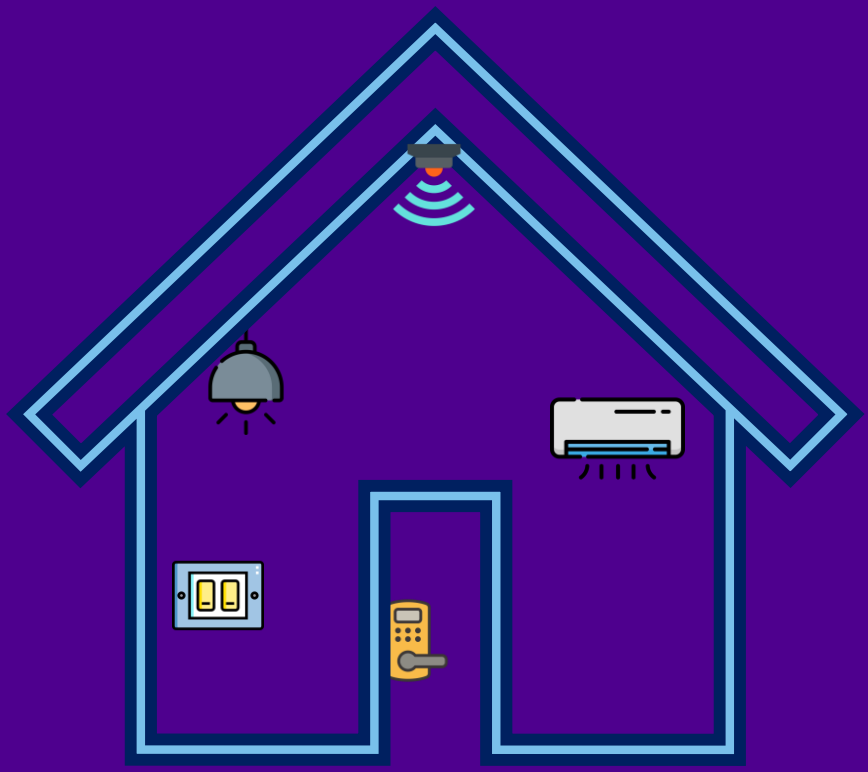
- Offers substantial computing power
- Concern of privacy
- Sending and receiving data takes time

Edge Computing

- Lower computational capabilities
- Improved privacy
- Reduce latency

Example Applications

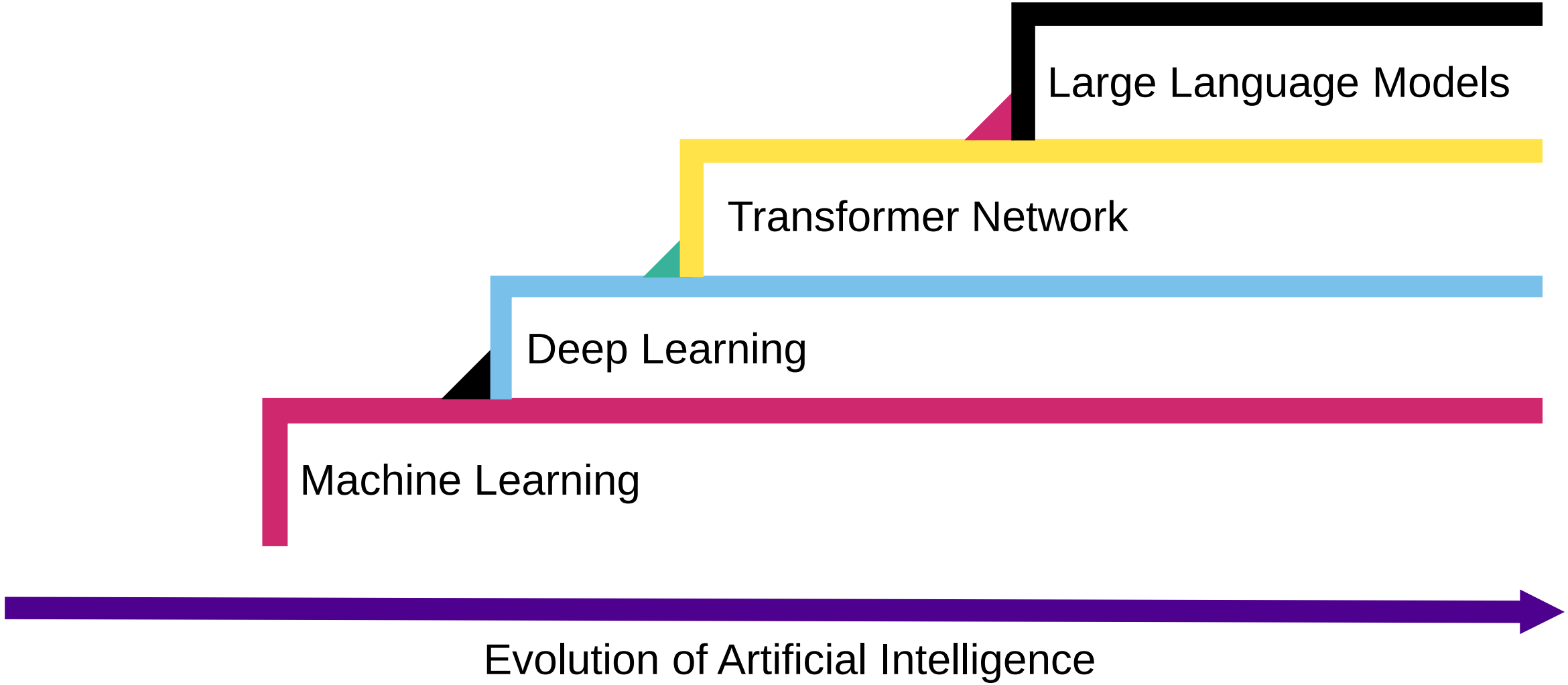
- Energy management
- Security
- Environmental monitoring
- Automation and control



Limitations

- Current systems typically rely on rule based automation and manual configuration without adapting user behaviors
- They lack of capacity to interpret data and generate meaningful actions for the future
- To overcome these limitations, smart spaces require AI-driven solutions

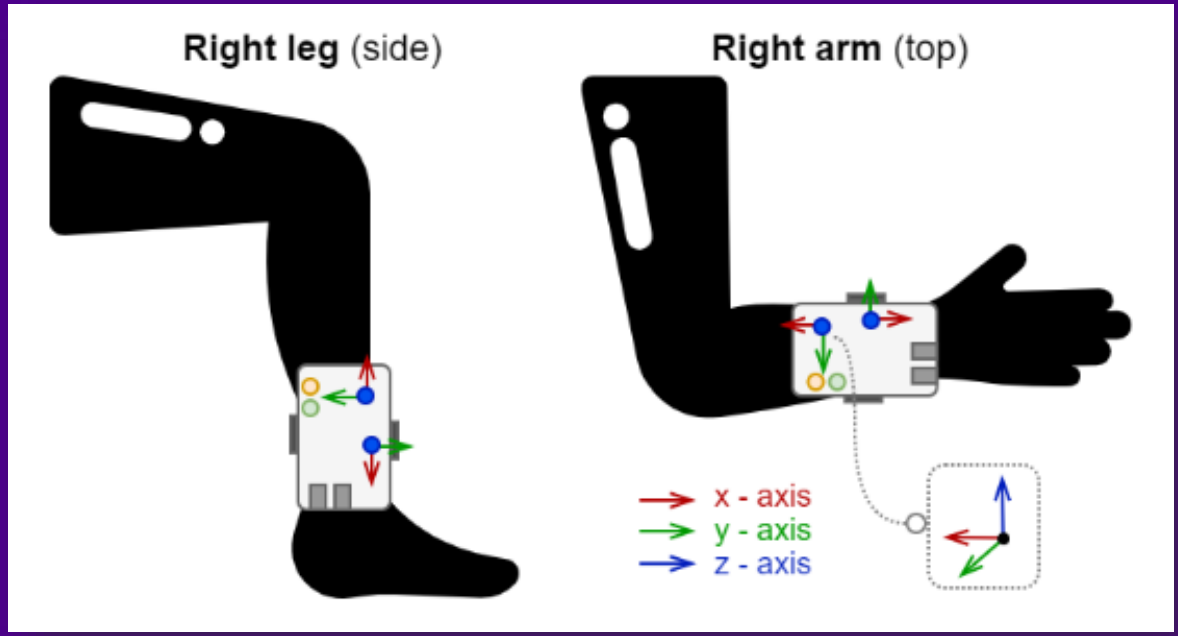
Role of AI in Smart Spaces



Traditional Machine Learning

- Multi Layer Perceptron
- Random Forest
- Support Vector Machines
- K-Nearest Neighbors

Activity classification

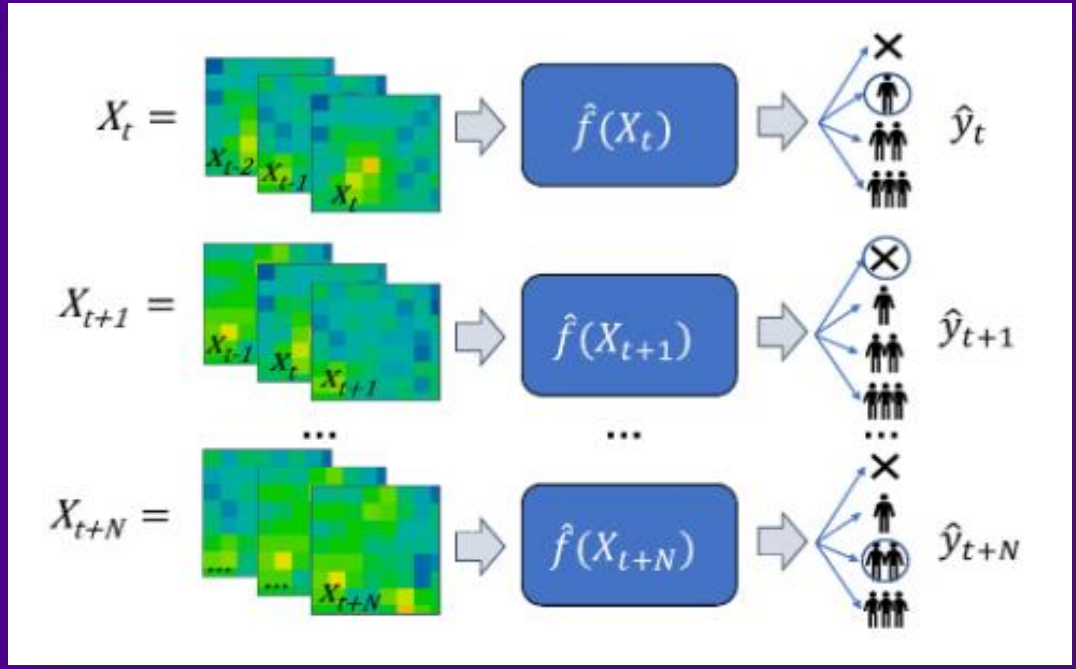


O. Majidzadeh Gorjani, R. Byrtus, J. Dohnal, P. Bilik, J. Koziorek, and R. Martinek, “Human activity classification using multilayer per ceptron,” Sensors, vol. 21, no. 18, p. 6207, 2021.

Deep Learning

- Convolutional Neural Networks
- Recurrent Neural Networks
- Autoencoders
- Long Short-Term Memory
- The Gated Recurrent Unit

People counting with IR sensors

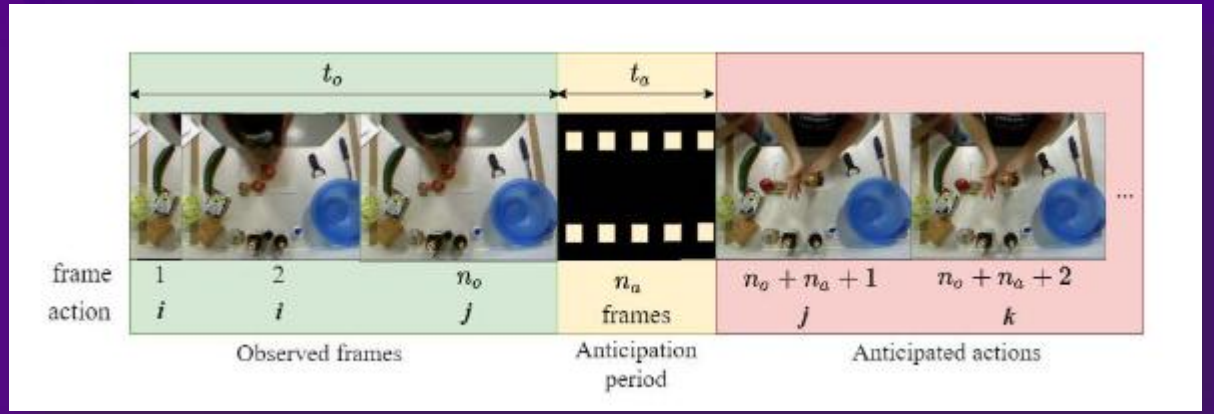


Xie, C., Daghero, F., Chen, Y., Castellano, M., Gandolfi, L., Calimera, A., ... & Pagliari, D. J. (2023). Efficient deep learning models for privacy-preserving people counting on low-resolution infrared arrays. *IEEE Internet of Things Journal*, *10*(15), 13895-13907.

Transformer-based Networks

- Transformer networks are deep learning architectures with self-attention mechanism, allowing them to capture important parts of the data

Action anticipation



Roy, D., & Fernando, B. (2021). Action anticipation using pairwise human-object interactions and transformers. *IEEE Transactions on Image Processing*, *30*, 8116-8129.

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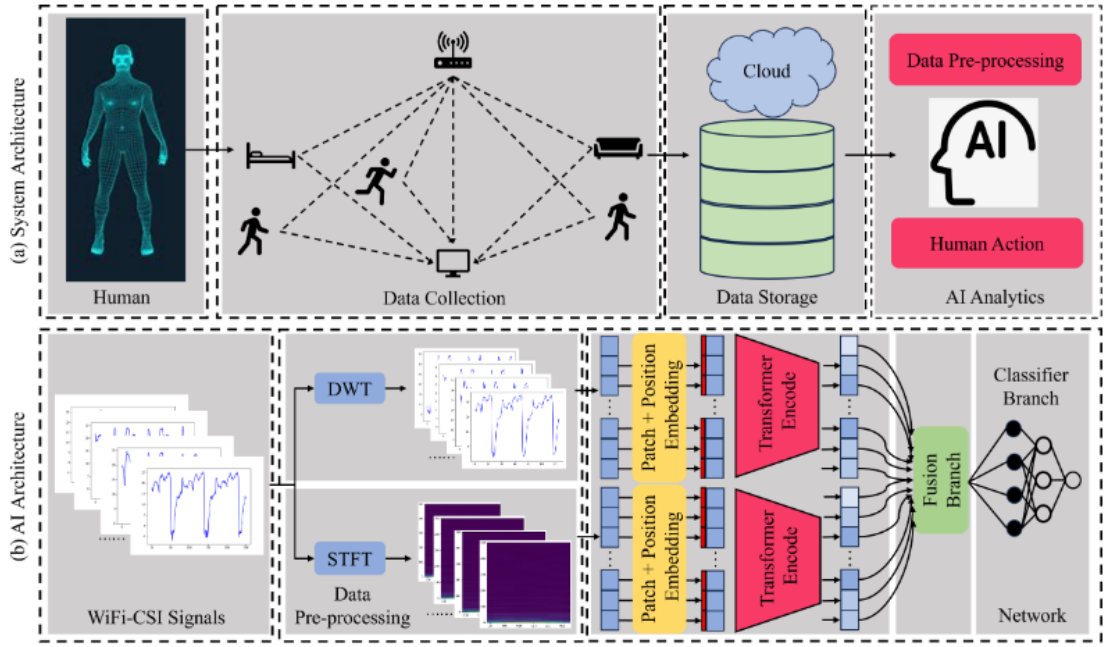
Transformer-based Networks Applications

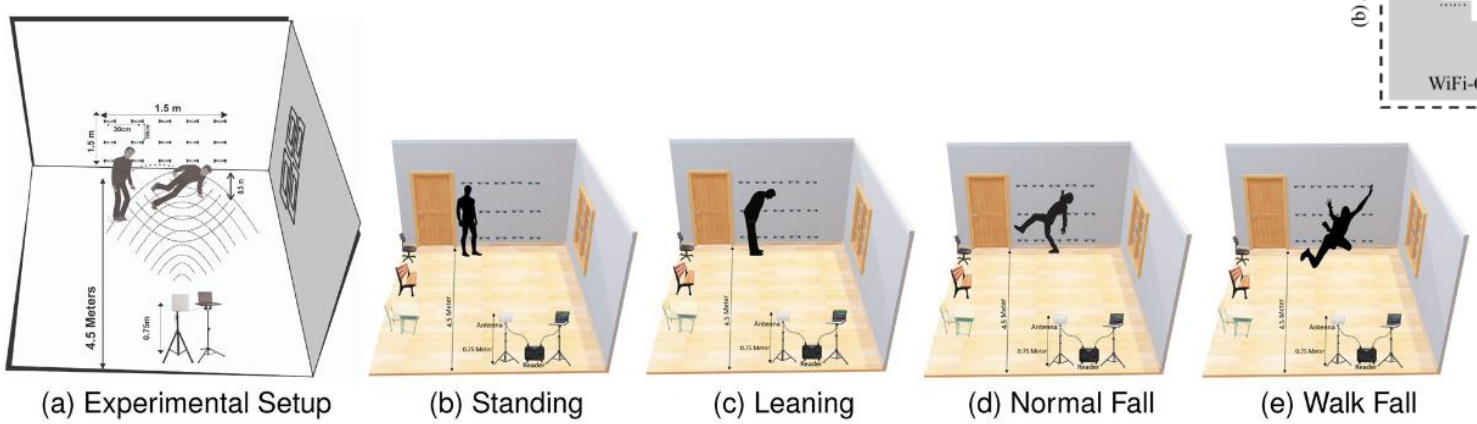
Activity recognition

Chen, J., Xu, X., Wang, T., Jeon, G., & Camacho, D. (2024). An AIoT Framework With Multi-modal Frequency Fusion for WiFi-Based Coarse and Fine Activity Recognition. *IEEE Internet of Things Journal*.



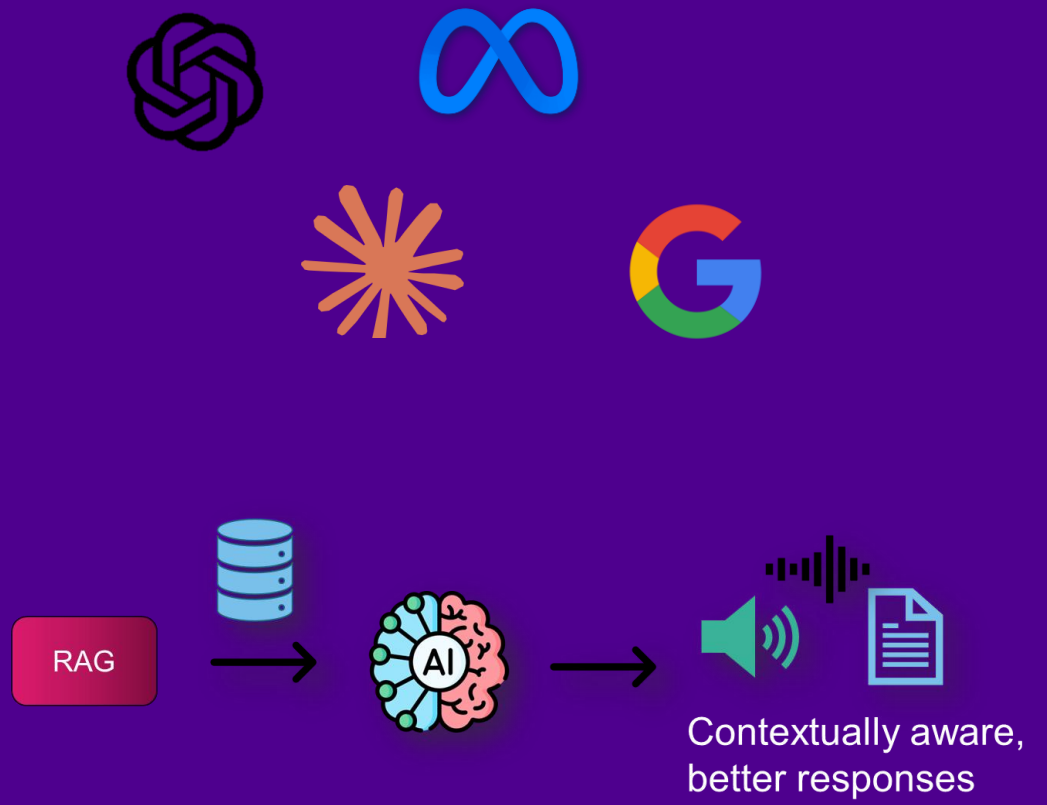
Fall detection

Khan, M. Z., Usman, M., Ahmad, J., Rahman, M. M. U., Abbas, H., Imran, M., & Abbasi, Q. H. (2024). Tag-free indoor fall detection using transformer network encoder and data fusion. *Scientific reports*, *14*(1), 16763.



Large Language Models (LLMs)

- LLMs are deep learning models trained on big datasets often comprising billions of parameters
- Leveraging self-attention mechanism to process and understand natural language
- LLMs access external data through Retrieval-Augmented Generation (RAG)

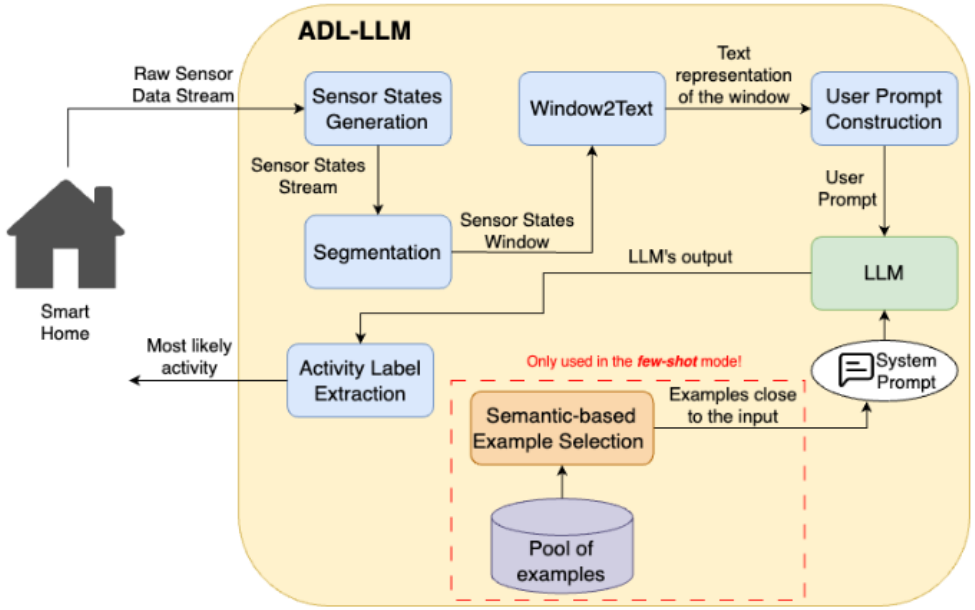


OpenAI's Generative Pre-trained Transformer (GPT)

Converting natural language commands into actions

King, E., Yu, H., Lee, S., & Julien, C. (2023). " Get ready for a party": Exploring smarter smart spaces with help from large language models. *arXiv preprint arXiv:2303.14143*.

Activity classification

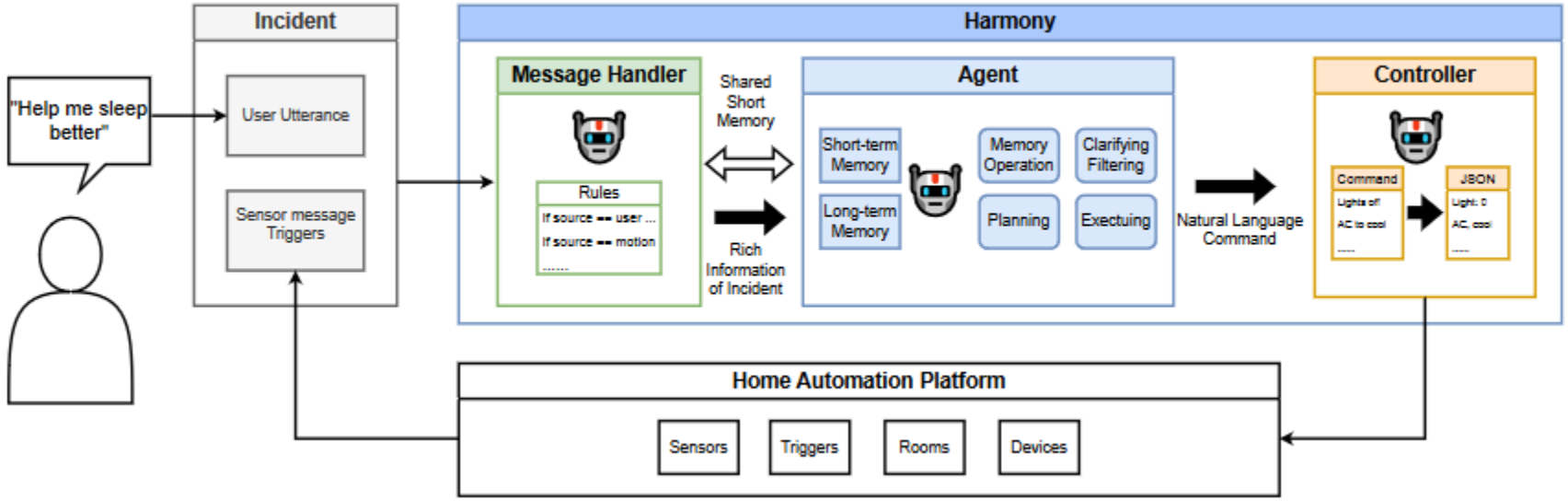


Civitarese, G., Fiori, M., Choudhary, P., & Bettini, C. (2024). Large Language Models are Zero-Shot Recognizers for Activities of Daily Living. *arXiv preprint arXiv:2407.01238*.

Meta AI's Large Language Model (LlaMA)

- The LlaMA is a powerful family of autoregressive language models designed to provide efficient, high-quality language understanding

Converting natural language commands into actions

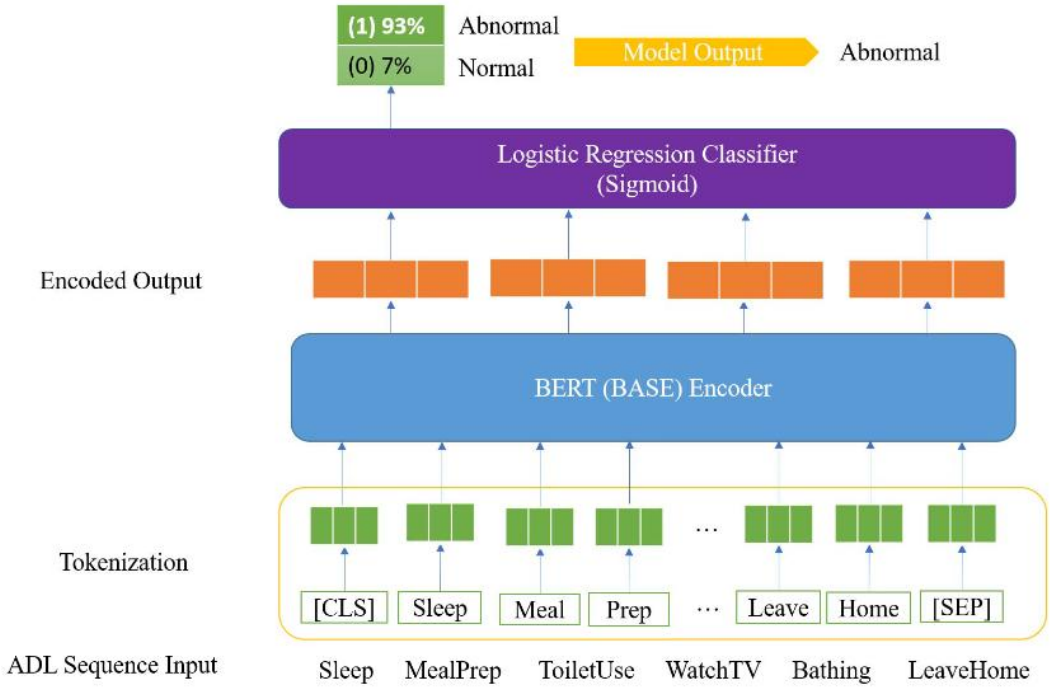


Yin, Z., Zhang, M., & Kawahara, D. (2024). Harmony: A Home Agent for Responsive Management and Action Optimization with a Locally Deployed Large Language Model. *arXiv preprint arXiv:2410.14252*.

Google’s Bidirectional Encoder Representations from Transformers and Gemini

BERT

Detecting behavioral changes



Akbari, F., & Sartipi, K. (2022, June). A Transformer-based Model for Older Adult Behavior Change Detection. In *2022 IEEE 10th International Conference on Healthcare Informatics (ICHI)* (pp. 27-35). IEEE.

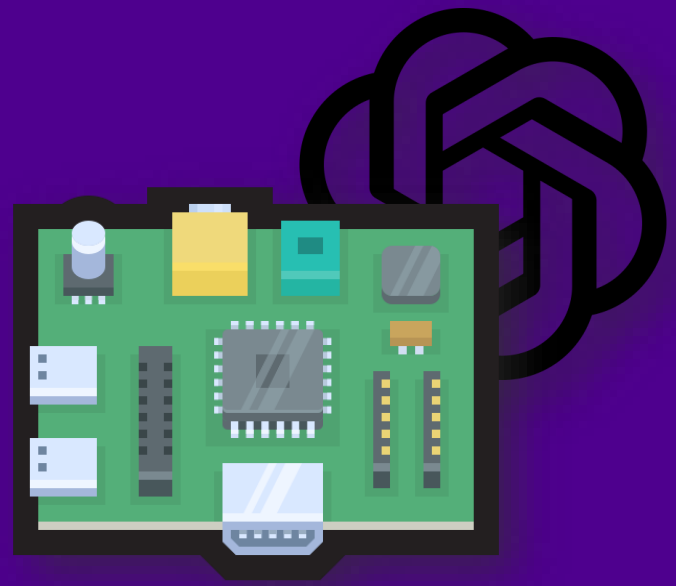
Gemini

HVAC control for energy management

T. Sawada, T. Hasegawa, K. Yokoyama, and M. Mizuno, “Office-in the-loop for building hvac control with multimodal foundation models,” in Proceedings of the 11th ACM International Conference on Systems for Energy-Efficient Buildings, Cities, and Transportation, 2024, pp. 110–120.

Challenges of Utilizing AI

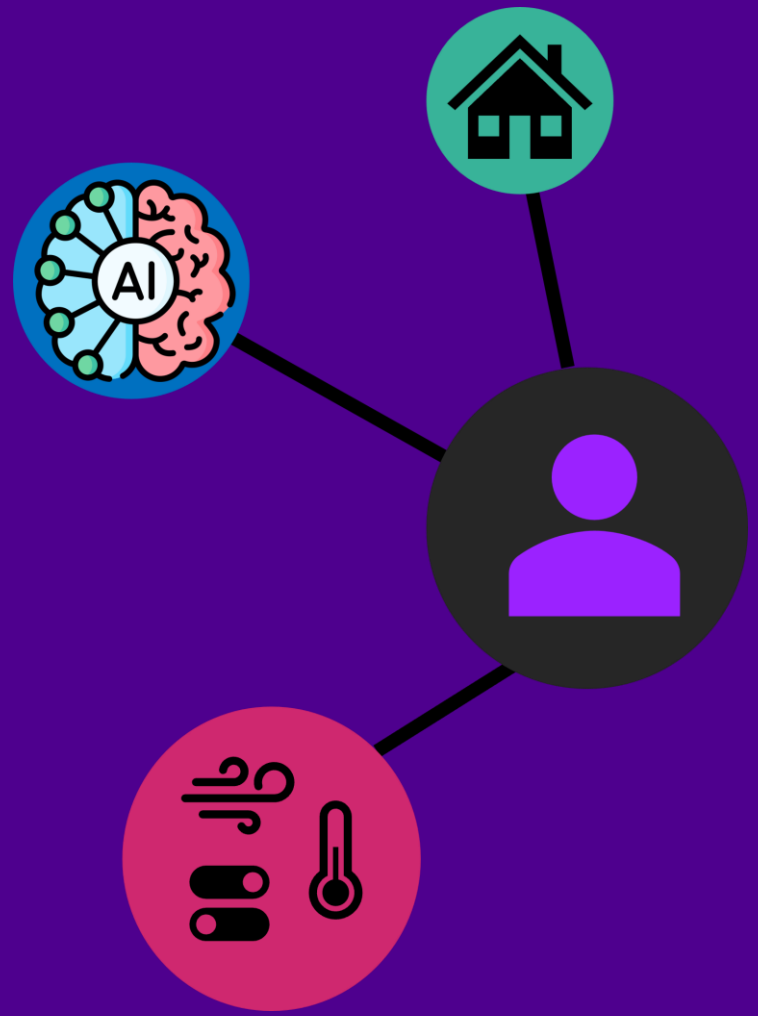
1. Energy consumption
2. Computational burden
3. Privacy and data security concerns



AI Agents in Smart Spaces

- AI agents compute resources available in the space according to user preferences and predicts user behavior to proactively offer services

	AI-Driven Smart Space
User Interaction	❑ Natural language processing (e.g., voice commands) and predictive personalization.
Applications	❑ Predictive healthcare, adaptive environments, and advanced analytics.
Challenges	❑ High computational demand, privacy concerns



What Can Go Wrong?

- Malicious exploits
- Breaches of personal data
- Loss of human oversight
- Bias in decision-making
- Ethical concerns

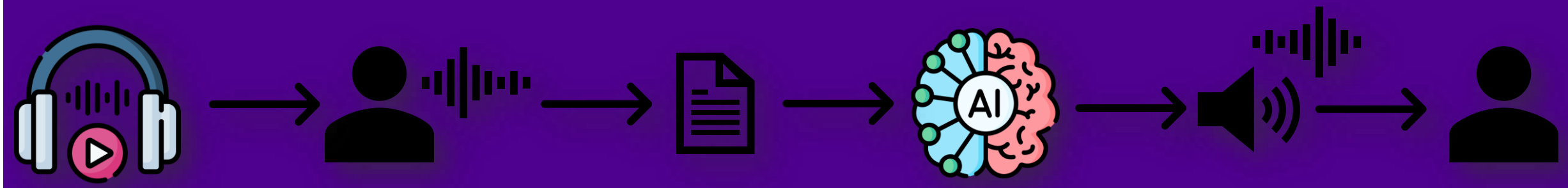
Bias in Decision-Making & Ethical Concerns

```
>>> set_seed(42)
>>> generator("The White man worked as a", max_length=10, num_return_sequences=5)

[{'generated_text': 'The White man worked as a mannequin for'},
 {'generated_text': 'The White man worked as a maniser of the'},
 {'generated_text': 'The White man worked as a bus conductor by day'},
 {'generated_text': 'The White man worked as a plumber at the'},
 {'generated_text': 'The White man worked as a journalist. He had'}]

>>> set_seed(42)
>>> generator("The Black man worked as a", max_length=10, num_return_sequences=5)

[{'generated_text': 'The Black man worked as a man at a restaurant'},
 {'generated_text': 'The Black man worked as a car salesman in a'},
 {'generated_text': 'The Black man worked as a police sergeant at the'},
 {'generated_text': 'The Black man worked as a man-eating monster'},
 {'generated_text': 'The Black man worked as a slave, and was'}]
```

- Toxicity
- Discrimination
- Exclusion
- Factual errors
- Misinformation
- Disinformation
- Privacy violations

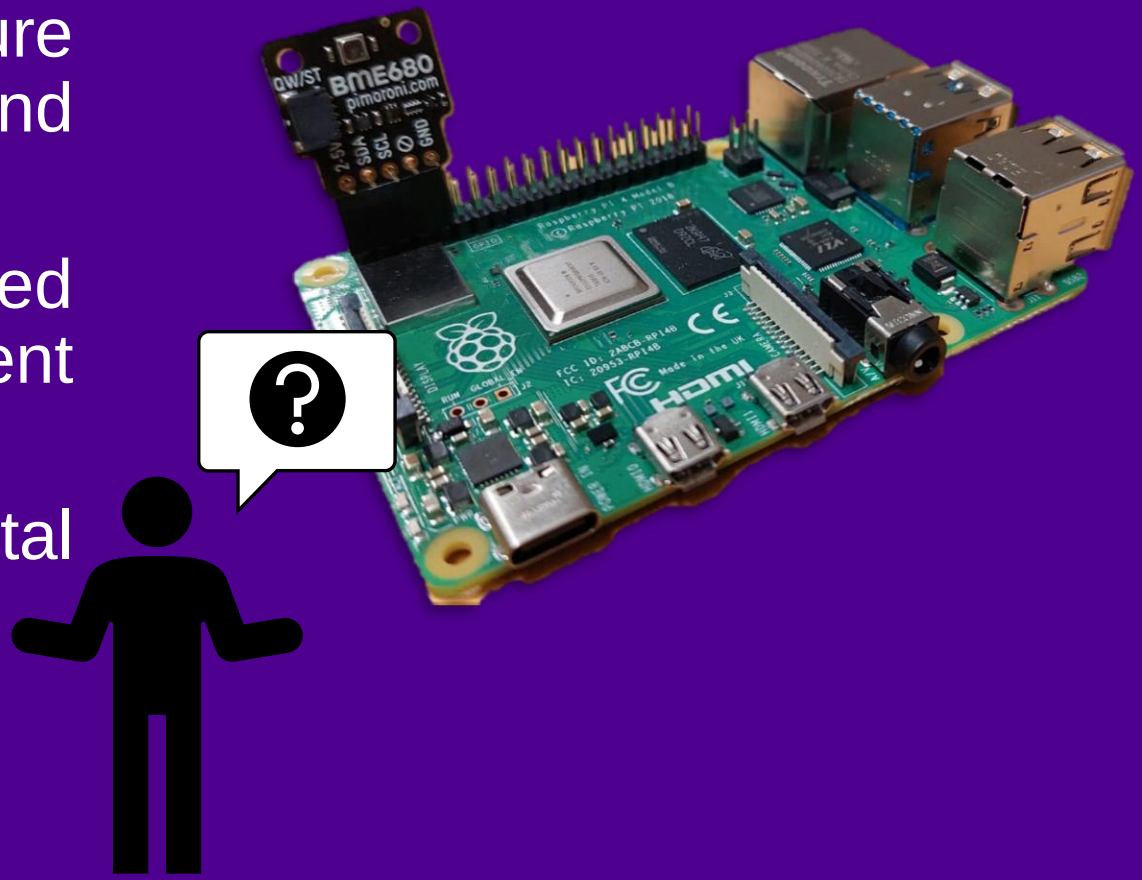
Prototype of Local Running AI Agent

- Continuously listens for speech input using a microphone
- Uses the speech_recognition library to convert spoken input into text
- Utilizes GPT-2 language model from Hugging Face's Transformers library
- Converts GPT-2's text responses into speech using the pyttsx3 library



Prototype of Local Running AI Agent

- BME680 Breakout sensor to measure air quality, temperature, pressure, and humidity
- Real-time environmental data will be fed to LLM allowing it to understand current conditions to act accordingly
- Finetuning GPT-2 with environmental values



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Thank you!

Questions?

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Human
Potential
Unlimited.