

# Bilateral Artificial Intelligence: The Road to Broad AI

Thomas Eiter  
Institute of Logic and Computation  
Vienna University of Technology (TU Wien)



# The Dawn of Artificial Intelligence



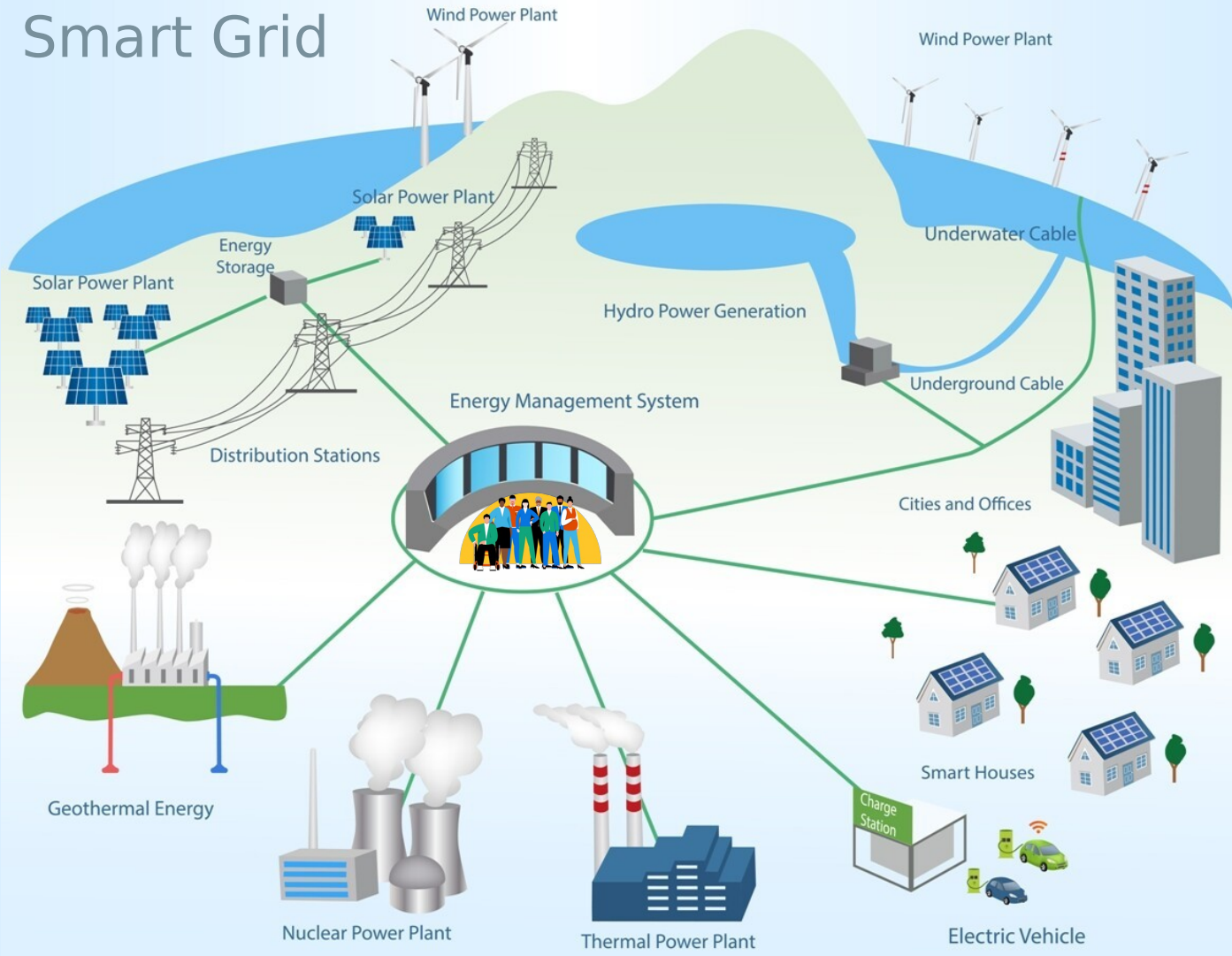
# Limited Artificial Intelligence

Since current **Artificial Intelligence (AI)** is limited, it insufficiently contributes to overcome crucial challenges concerning

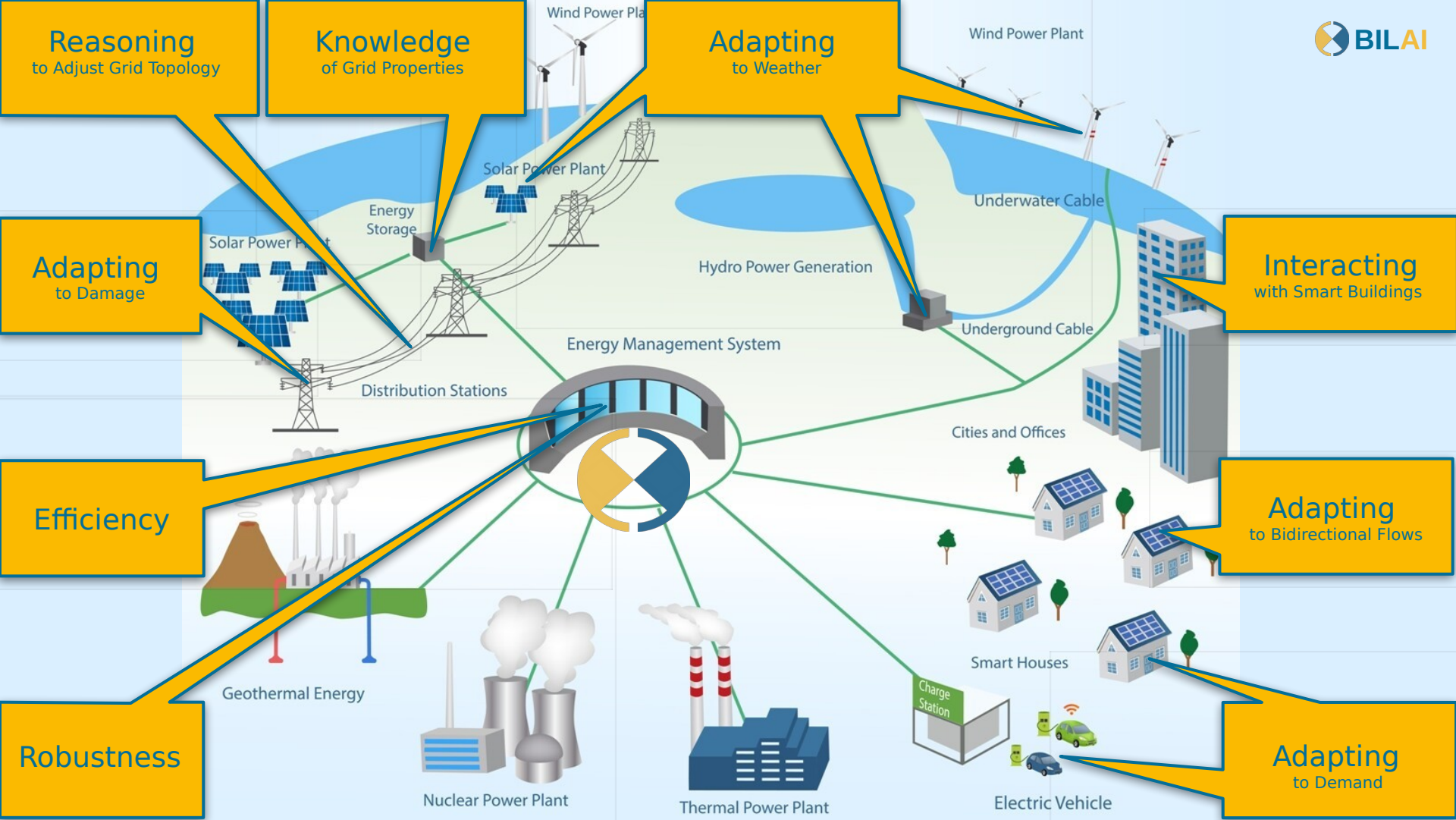
- **Energy**
- **Climate**
- **Food**
- **Healthcare**
- **Mobility**



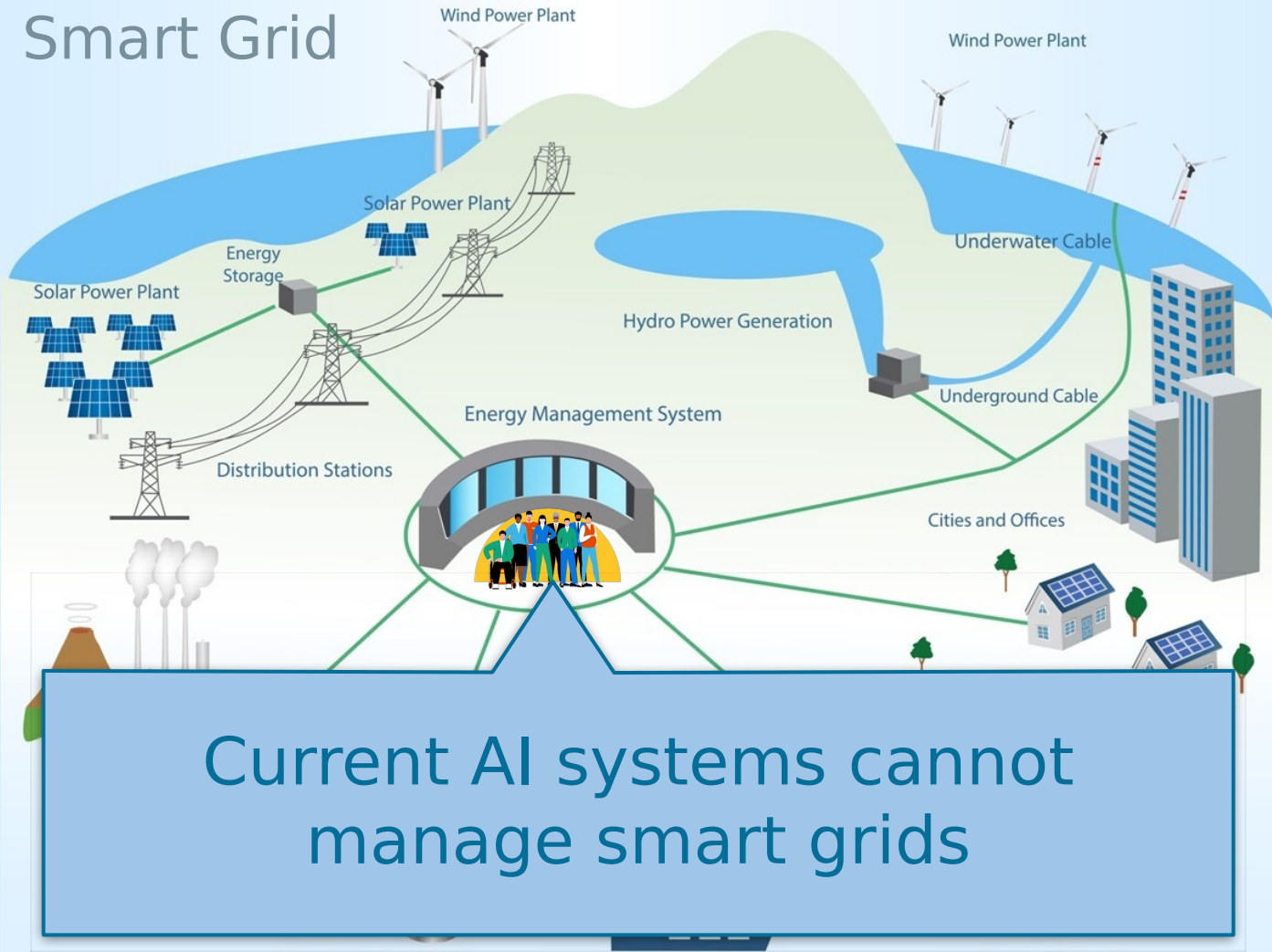
# Energy: Smart Grid





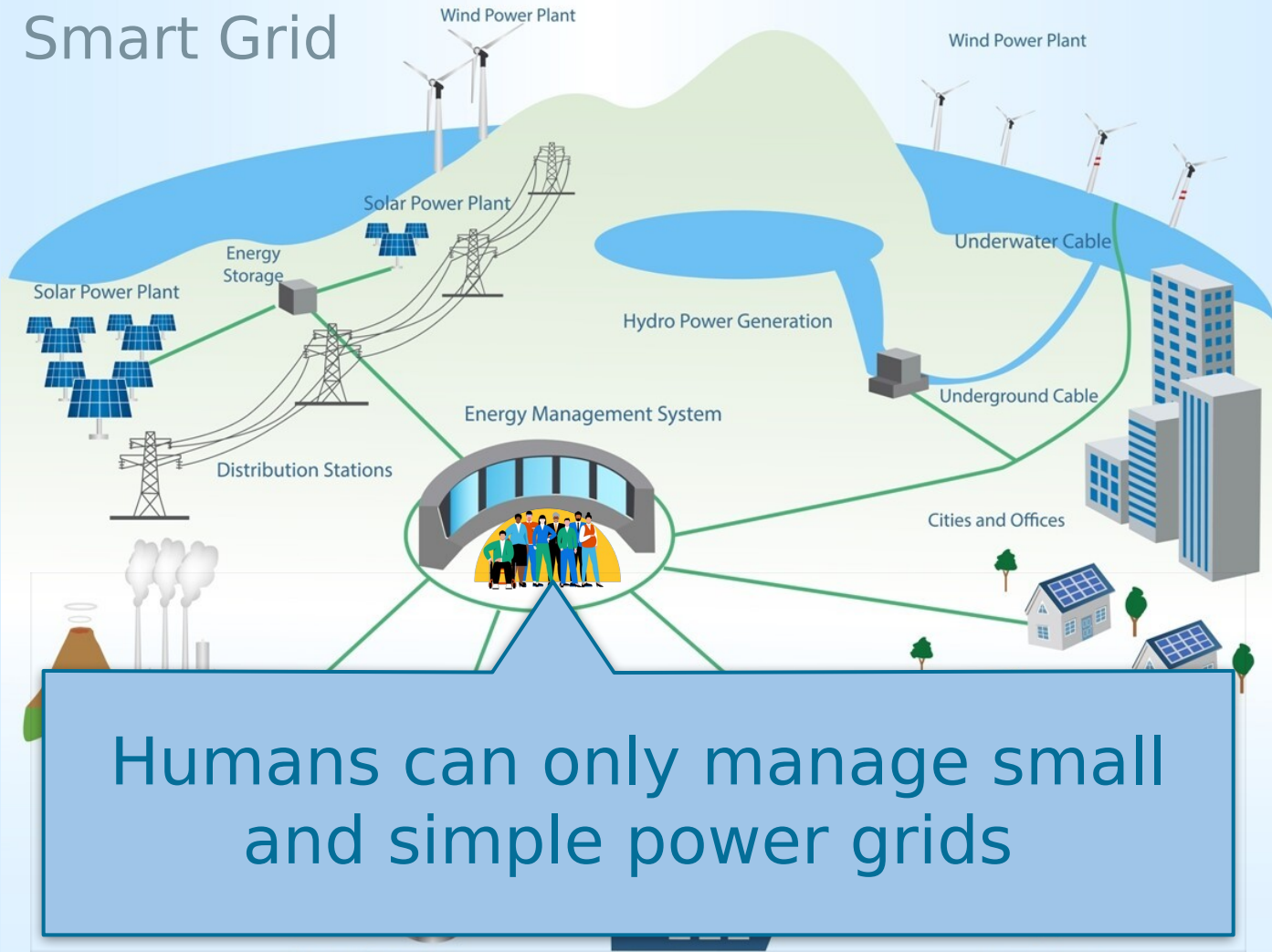


# Energy: Smart Grid



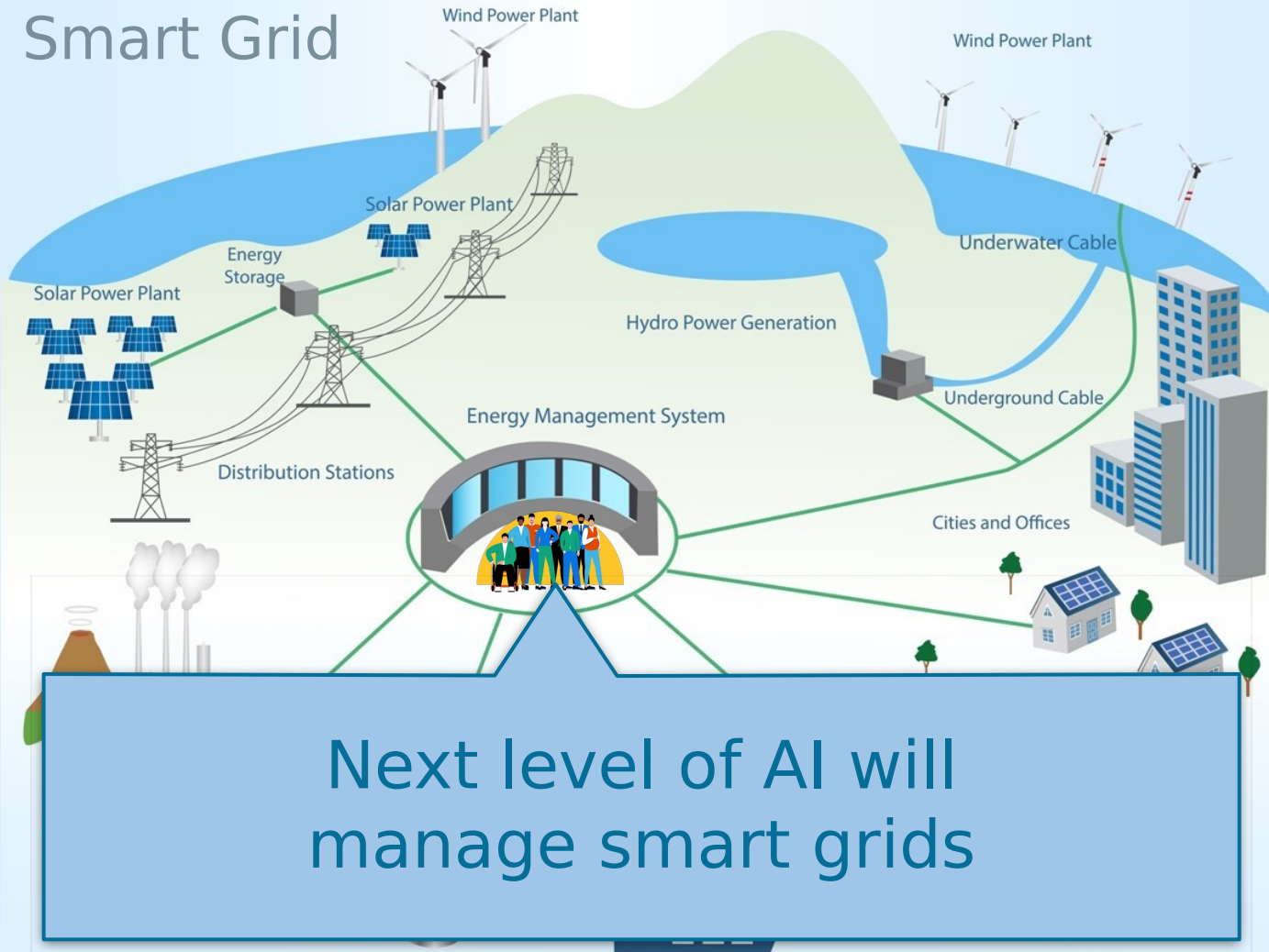
Current AI systems cannot manage smart grids

# Energy: Smart Grid



Humans can only manage small and simple power grids

# Energy: Smart Grid



Next level of AI will  
manage smart grids



# Artificial Intelligence

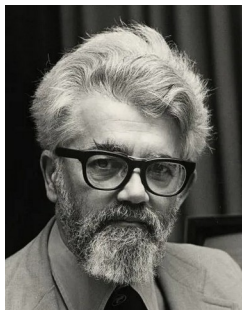
*“AI is a machine that **exhibits cognitive functions like humans** such as learning, planning, reasoning, problem solving, and skill acquisition.”*

Barr & Feigenbaum, 1981

**1956**

John McCarthy  
coined the term

**Artificial Intelligence**

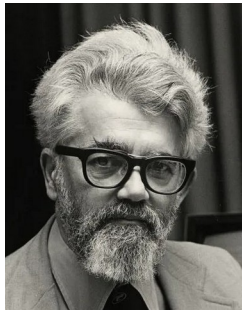


# Artificial Intelligence

**1956**

John McCarthy  
coined the term

**Artificial Intelligence**



**1997**  
Deep Blue



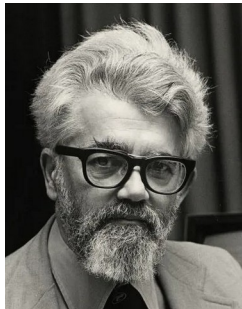
**2011**  
IBM Watson



**Symbolic AI**

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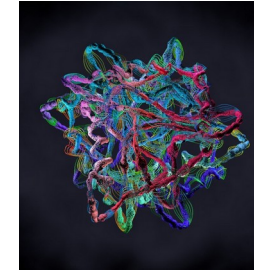


**2011**  
IBM Watson



**Symbolic AI**

**Sub-symbolic AI**



**2018**  
AlphaFold



**2022**  
ChatGPT

# Symbolic AI

## Concepts and goal

- Reasoning, logic and knowledge representation
- Searches for solutions at higher levels

## Advantages

- Abstraction and first principles
- Transparent and explainable
- Transferable
- Consistent and correct



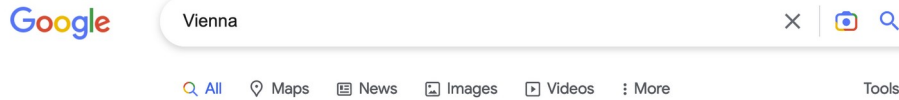




# Container terminal optimization

# Invisible Symbolic AI: Knowledge Graphs

When you search, you use symbolic AI



About 722.000.000 results (0,58 seconds)

<https://en.wikipedia.org/wiki/Vienna>

## Vienna - Wikipedia

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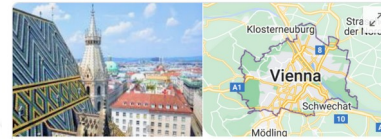
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 Demyonym(s): [German: Wiener \(m\)](#), [Wien...](#) GDP per capita: € 50,400 (2020)

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**Local time:** Friday 10:23

**Population:** 1.897 million (2019) Eurostat

**Mayor:** Michael Ludwig

**Clubs and Teams:** FK Austria Wien, SK Rapid Wien, MORE

### Colleges and Universities

View 25+ more



### Points of interest

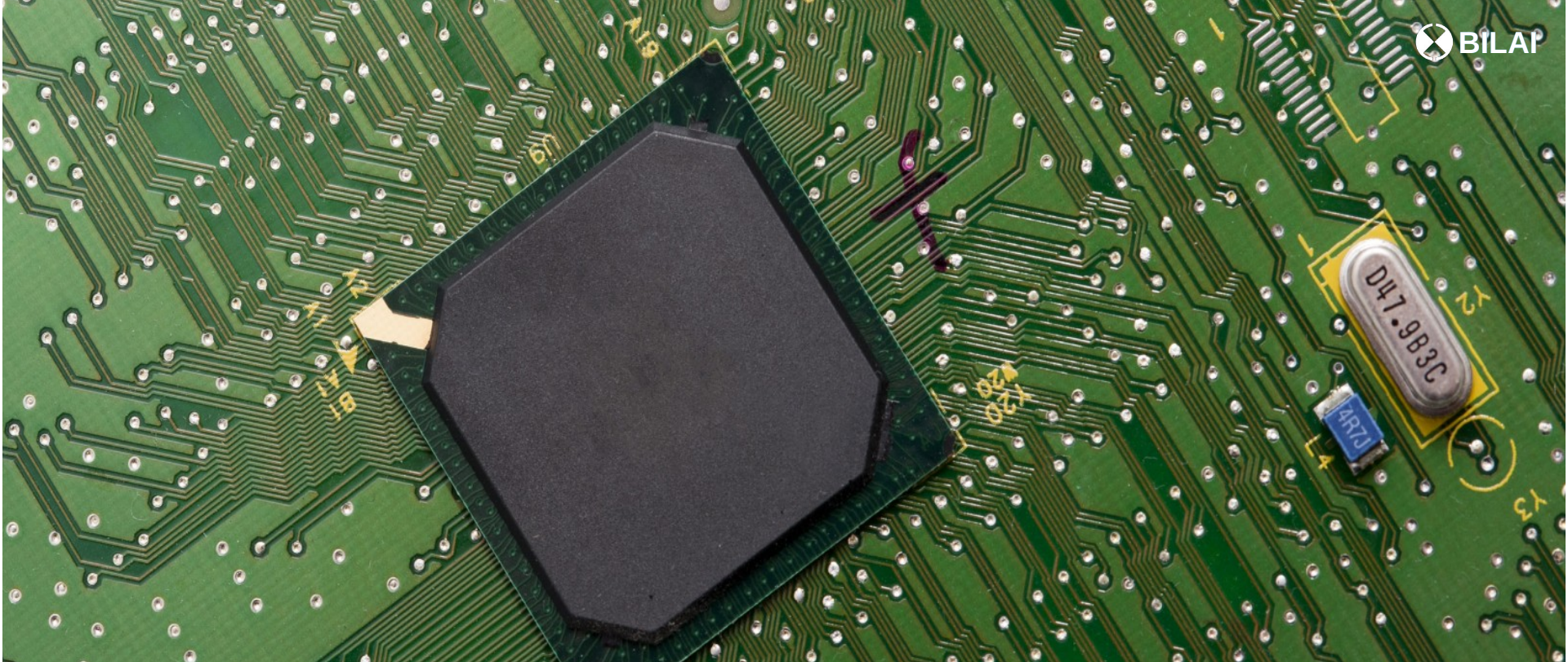
View 20+ more



- cities
- points of interest
- universities etc. ...



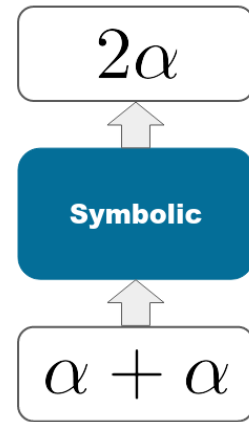




Verification of chip correctness  
Optimization of circuit design

# Limitations of Symbolic AI

- Computationally expensive
- Less amenable for sensory inputs and continuous physical systems
- Highly engineered for particular application domains

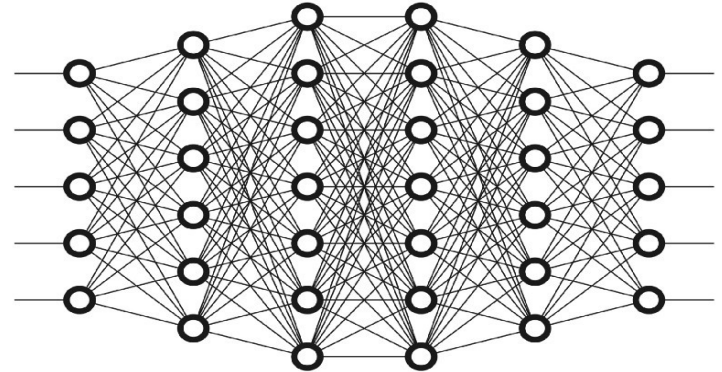




# Sub-symbolic AI

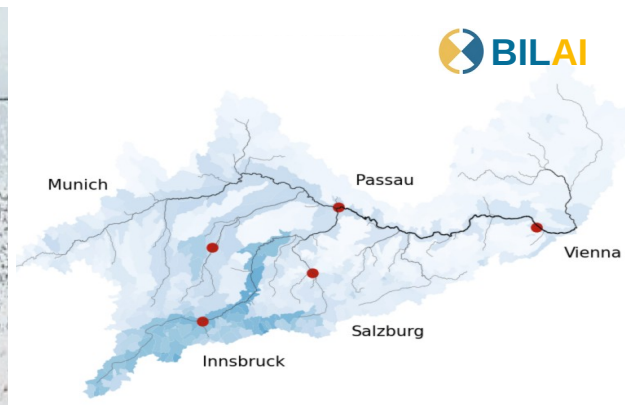
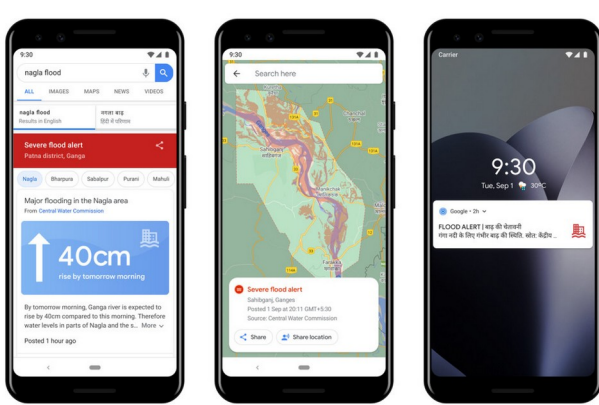
## Concepts and goal

- Learning from data and automatically constructing representations
- Solving tasks from data without human deduction of solutions
- Deep Learning is the key technology.



## Advantages

- Works for unstructured data (images, text, acoustic, sensors)
- Learns features and data representation automatically
- Scales well with problem size
- Solves problems end-to-end without orchestrating components

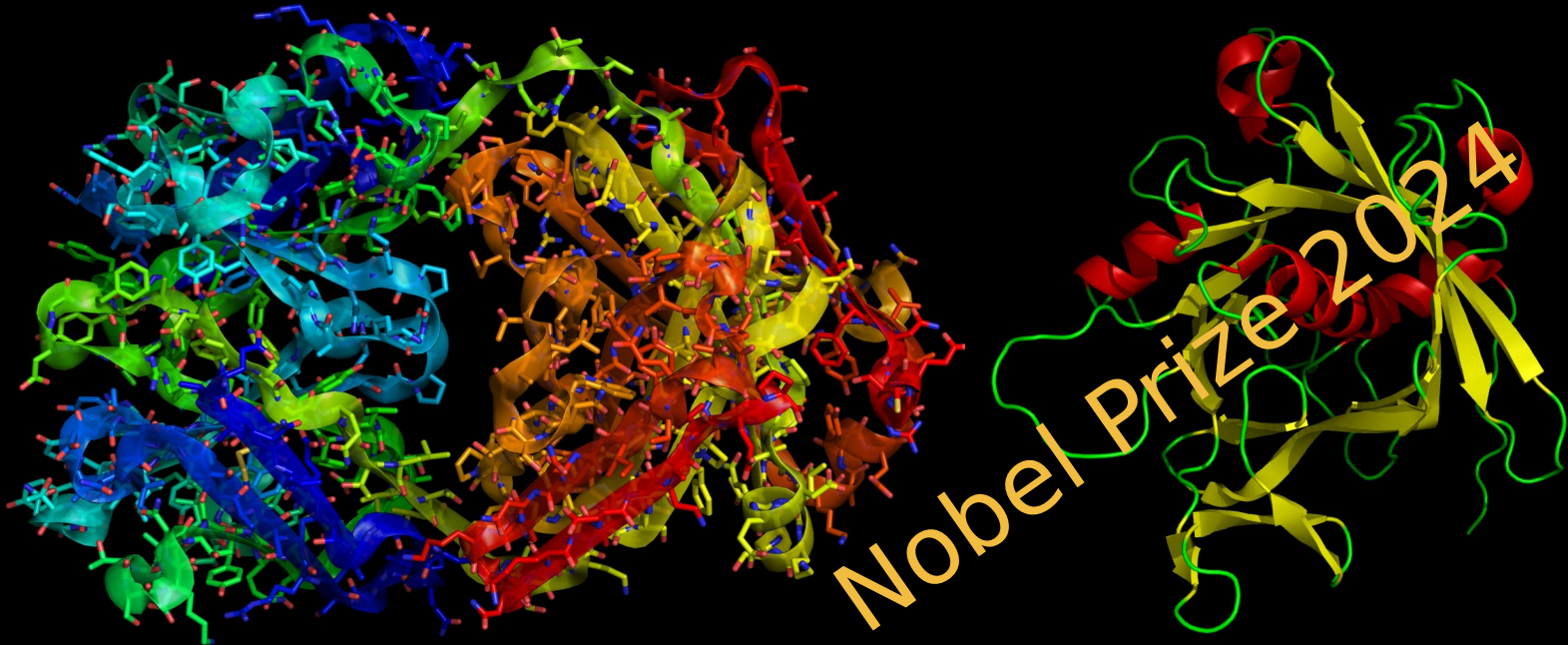


LSTMs predict floods and droughts





# AlphaFold



AI Breakthrough in Biology

 DALL-E 2



"teddy bears mixing sparkling chemicals as mad scientists in a steampunk style"

 BILAI

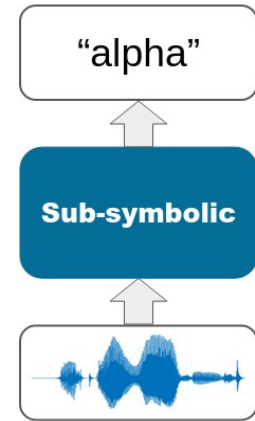
CHAT  
GPT 



# Limitations of Sub-symbolic AI

Sub-symbolic AI struggles with

- incorporating **world** and **prior knowledge**
- quickly adapting to **changing tasks** and **environments**
- learning with **small data** and restricted **computing resources**
- correcting **biases** in data



# Benefits of LLMs

LLMs can be fruitfully used for

- text summarization
- format conversions
- text to formal language (code, SQL, etc.) and back
  - interfacing (symbolic) systems
- blurb text generation
- making suggestions
- conversational entertainment (cf. Eliza, 1968)
- ...



# Limitations of LLMs

LLMs cannot really

- do deeper reasoning, fail on
  - planning, spatial reasoning, verification (chain of thoughts insufficient )
  - explanations
- handle common sense
- do proper abstraction
- learn with little data and restricted computing resources
- correct biases in data and deal with ethics and norms



# Some Derived Issues

Need for

- taming hallucination
  - Inject reasoning, semantic constraints
- proper usage of (external) software and tools
  - meta-knowledge
  - understanding of semantics
- contextualization
  - recognize intentions



**Are LLMs a dead end ? LeCun [AAAI 24]**

# Challenge: Bridge Divided Fields

**Basis:** logic

**Tools:** discrete mathematics

**Data:** structured (tables, graphs)

**Basis:** probability

**Tools:** continuous mathematics

**Data:** unstructured (images, texts)

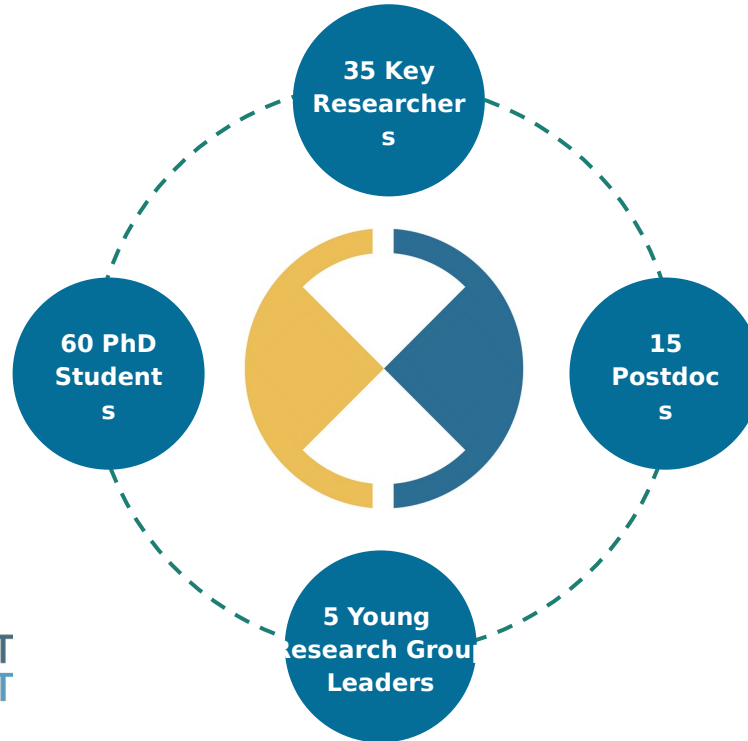


Symbolic AI



Sub-symbolic AI

# BILAI Cluster





# Our Vision

To lay the foundation for a **next level of Artificial Intelligence** that goes beyond the current specialized AI systems



# Our Vision

To lay the foundation for a **next level of Artificial Intelligence** that goes beyond the current specialized AI systems



We envision **Broad AI** (term coined by Chollet, 2019)

- **Robust**
- **Adaptive**
- **Interacting**
- **Ethical**



Human cognitive abilities

**General AI**  
Human level abilities

Knowledge  
&  
Interaction

Adaptability  
&  
Robustness

Abstraction  
&  
Reasoning

Efficiency

**Broad AI**  
Broad cognitive abilities

Image  
generation

DALL·E 2

Language  
processing

ChatGPT

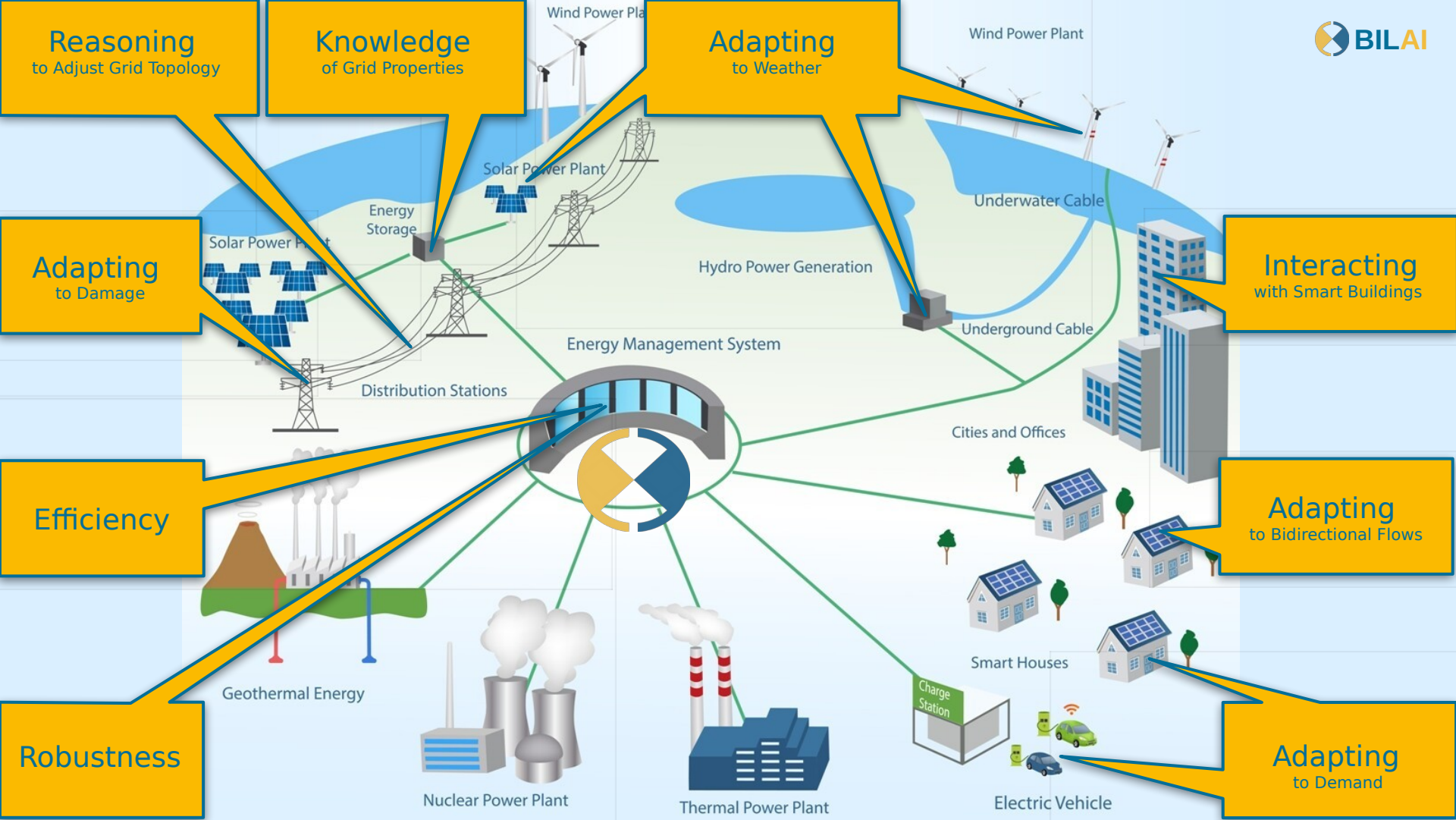
Game  
playing

AlphaGO

Structure  
prediction

AlphaFold

**Narrow AI**  
Task specific skills





# Upper Benchmark: HAL

2001: A Space Odyssey (Kubrik, 1968)

vision

language understanding

game playing

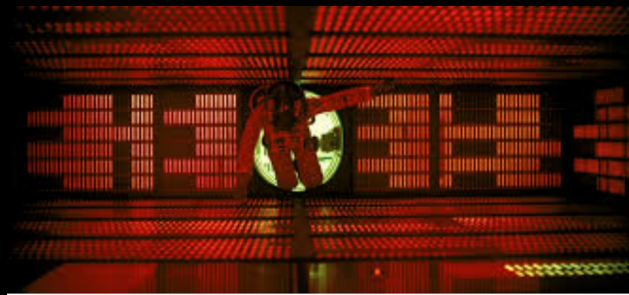
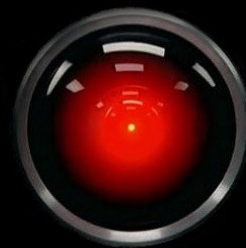
real world reasoning

planning

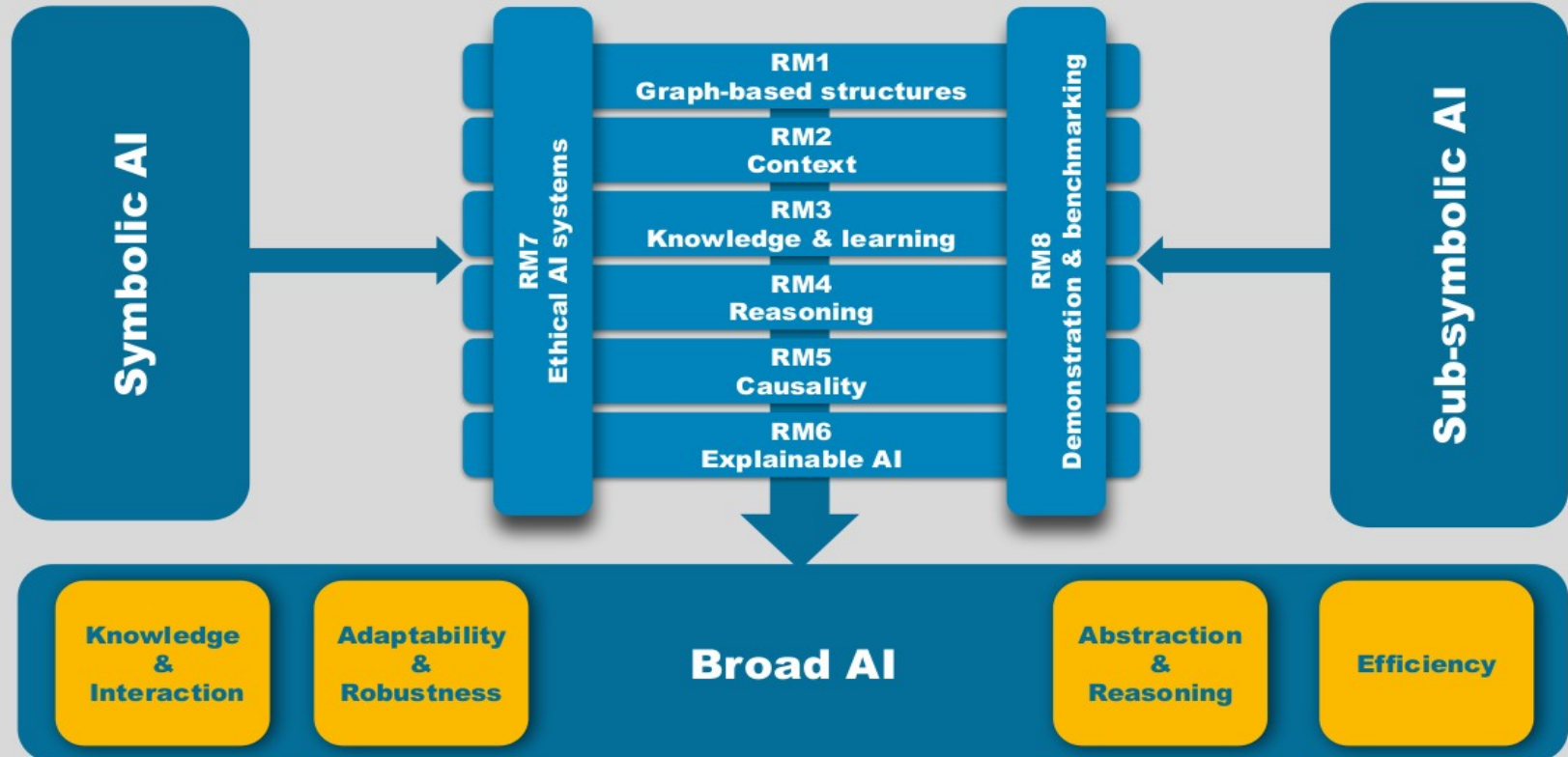
art and aesthetics

robotics (inherently)

Assessment in 2001: far from that  
some progress since  
full scale: Artificial General AI



# Bilateral AI



# BILAI Research Challenges

- Use symbolic knowledge in sub-symbolic systems
- Learn symbolic representations from data
- Exact symbolic reasoning with efficient sub-symbolic inference
- Integrate sub-symbolic learning with expert rules
- Use symbolic methods to generate explainable sub-symbolic AI
- Fuse sub- and symbolic AI to improve fairness of AI systems
- ...

Strong overlap with *Neuro-Symbolic AI*, yet broader in scope & collaboration

# Synergies

Symbolic AI Key Researchers

RM1: Graph-based structures

A P C L E S G K M M M S S S H T E T P

RM2: Context

A P E S G G G K R L S H T L W F W M

RM3: Knowledge & learning

A C D E JF G G G K M R S T T P W F  
C L A S S F G K C S P S L P F

RM4: Reasoning

G G G JF K M M M M N R S S S T E T W  
F G K C Y G O S S M P H S S W E P F

RM5: Causality

A F G K M R R S S T T  
P W K H S G P S M L P

RM6: Explainable AI

A F JF K M M S T T  
C W H S O S E L

RM7: Ethical AI systems

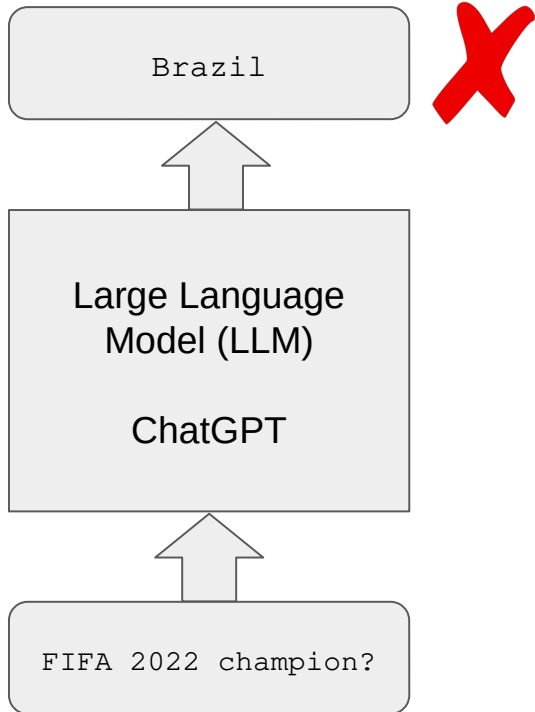
A A C D E F G JF M M N R R S T T  
C P L J L W G M O S M L P K E L  
A C D S S S H T L W  
P L A S H T L F

Sub-symbolic AI Key Researchers

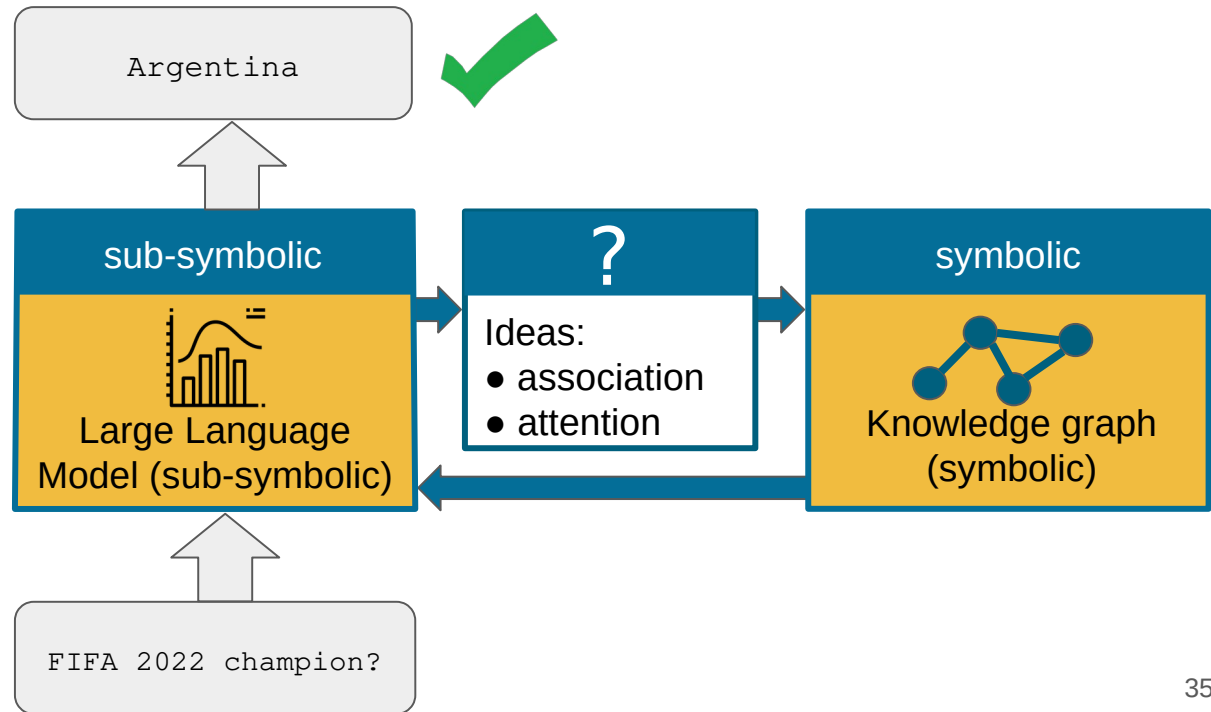


# Example Project RM2.1

Current AI system

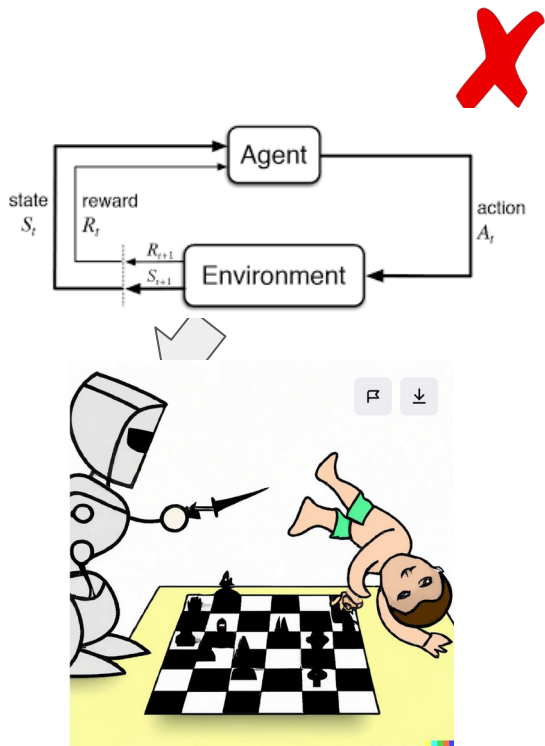


Bilateral AI system

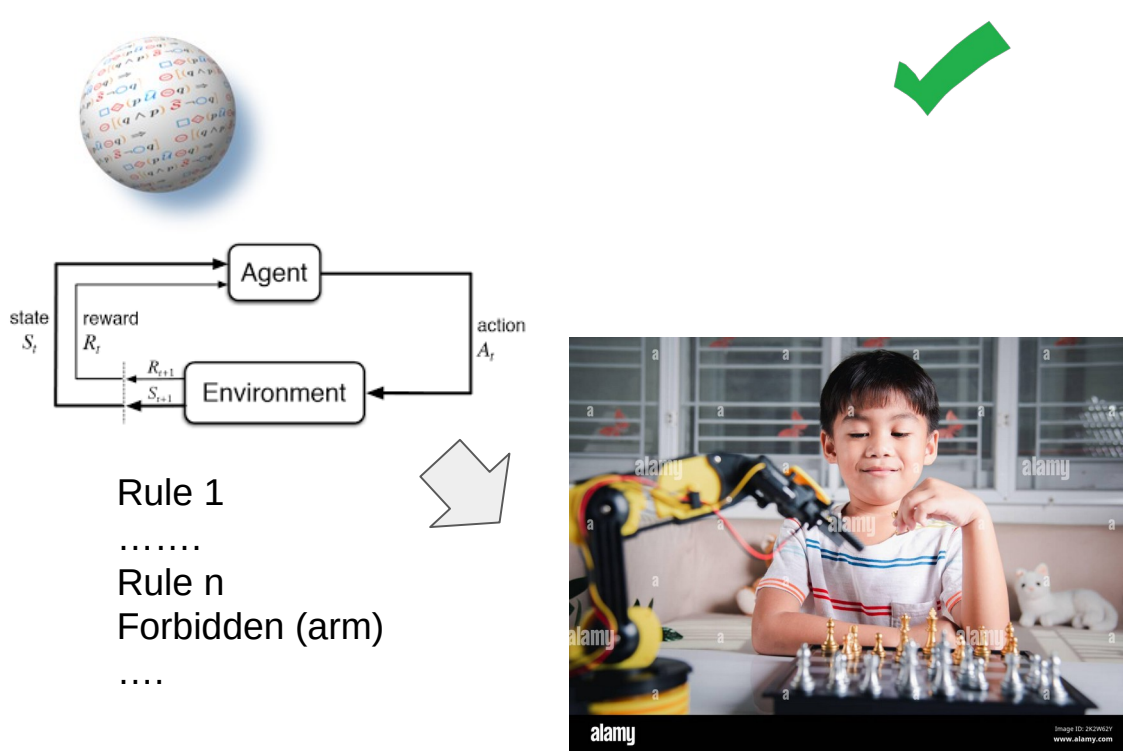


# Example Project RM7.3

Current Autonomous Agent



Bilateral Autonomous Agent



# Impact

A Broad AI facilitated by BILAI will

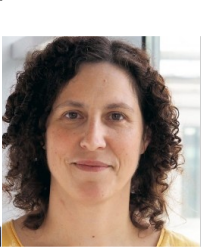
- have an enormous impact on **economy and society**
- be an enabling technology to tackle challenges concerning
  - **Energy**
  - **Climate**
  - **Food**
  - **Healthcare**
  - **Mobility**
- comply with **norms and ethics**
- assure a **democratization of AI**
- make **Europe more prominent** on the AI landscape



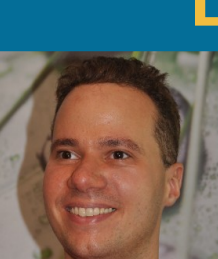
# Conclusion

- AI is on the rise, but current systems are specialized
- **Broad AI:** more **robust, adaptive, interactive & ethical** systems
- **Bilateral AI:** provide tools and methods to facilitate it
  - bridge sub-symbolic and symbolic AI  
(advocated by current ML critics, e.g. Gary Marcus)
- **BILAI** gathers researchers from both sides of AI
  - Cross-disciplinary collaboration
- Long-term horizon (methods, architectures & control)





# BILAI



**END**



**Martina Seidl**

Symbolic AI  
SAT Solving  
Formal methods

- Institute for Machine Learning
- ELLIS Unit Linz
- LIT AI Lab
- Institute for Symbolic Artificial Intelligence



**Sepp Hochreiter**

Machine Learning  
LSTM  
Vanishing gradient



**Christoph Lampert**

Machine Learning  
Trustworthy Learning

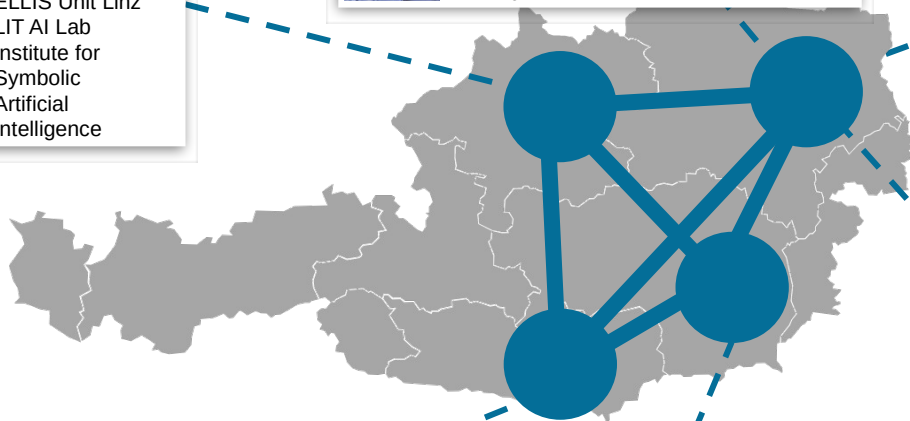
- Machine Learning and Computer Vision group
- ELLIS Unit ISTA



**Axel Polleres**

Knowledge Graphs

- Institute for Data Process and Knowledge Management



**Gerhard Friedrich**

Symbolic AI  
Model-based reasoning

- Institute for Artificial Intelligence and Cybersecurity



**Robert Legenstein**

Machine Learning  
Computational Neuroscience

- Institute of Theoretical Computer Science



**Agata Ciabattoni**

Logic Reasoning

- Institute for Logic and Computation

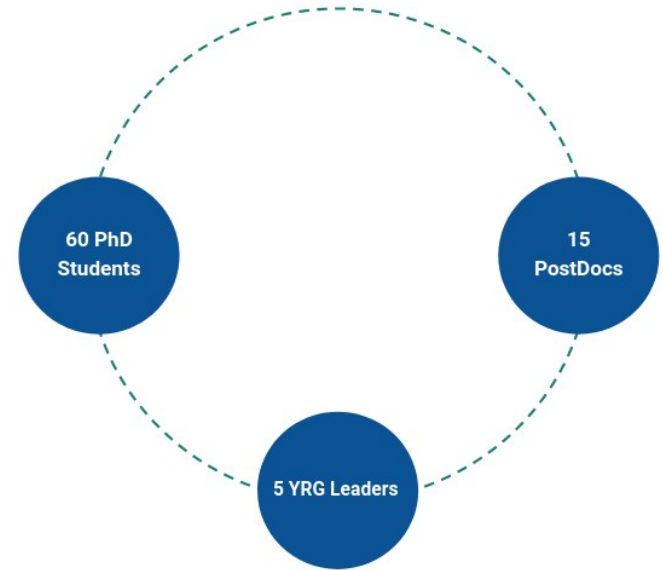


**Thomas Eiter**

Symbolic AI  
Knowledge representation

# Training Program

- **PreDocs**
  - BILAI Doctoral School
  - support for MSc and undergraduate students
- **PostDocs**
  - short (2 years) to longer term (4 years)
- **Junior Faculty (Young Research Groups)**
  - independent, own resources
  - tenure track or equivalent
  - new and further expertise: **AI Ethics, Green AI, ...**

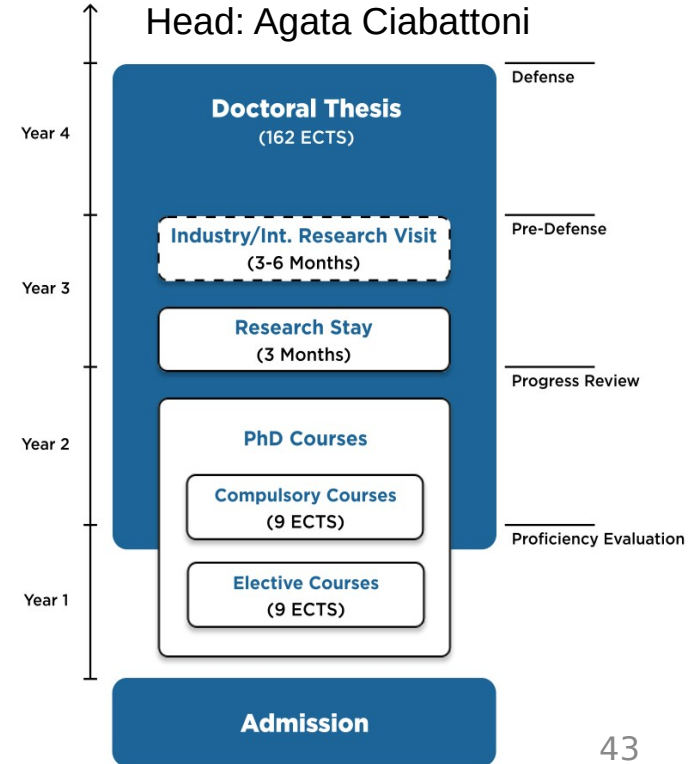




# Training I: Doctoral School

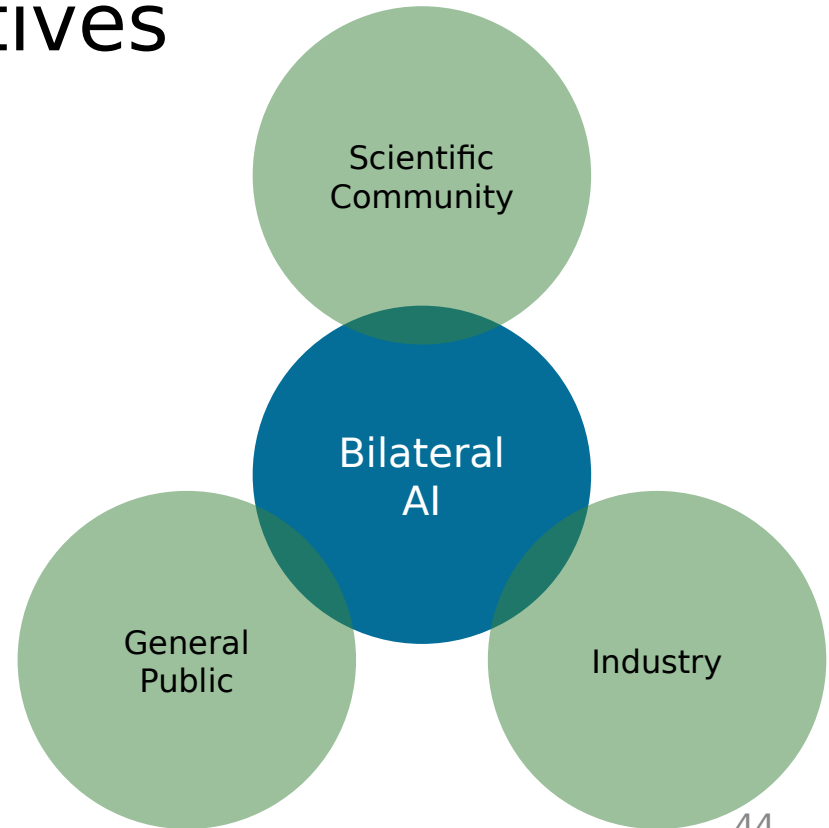
Unique education in symbolic and sub-symbolic AI,  
holistic training in the academic trade

- **Extensive experience**
  - FWF DK, MSCA Cofund, ...
- **Innovative elements**
  - 2 supervisors (symbolic AI + sub-symbolic AI)
  - mandatory courses in symbolic / sub-symbolic AI
  - visits (cluster, int'l top institution or industry lab)
  - diversity support and mentoring
  - exploitation & innovation
  - proposal writing, own meeting organization



# Communication & Transfer: Stakeholders and objectives

- Disseminate to and discuss with the scientific community
- Engage the general public
- Foster technology transfer and entrepreneurship, IPR





PIENSE

ΣΚΕΨΟΥ



THINK

ΣΜΑΧΗΝΙΣ

DENKE

सोचिए

PENSER

\$300,000

Who is Stoker?  
(FOR ONE WELCOME OUR  
NEW COMPUTER OVERLOADS)  
\$ 1,000

\$1,000,000

Who is Bram  
Stoker?  
\$ 17,973

\$200,000

WHO IS  
BRAM STOKER?  
\$5600

IBM Watson  
won Jeopardy

# A Broad AI

would have essential properties like

- performing complex **interactions** with humans
- ability to acquire new **knowledge**
- advanced **reasoning**

it could



**organize a journey**

with low CO2 emission



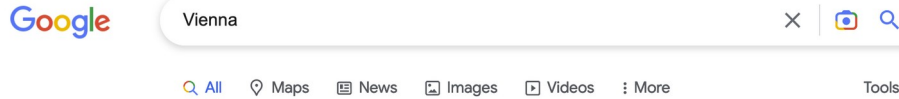
**plan the renovation**

with small ecological footprint 46



# Invisible Symbolic AI: Knowledge Graphs

When you search, you use symbolic AI



About 722.000.000 results (0,58 seconds)

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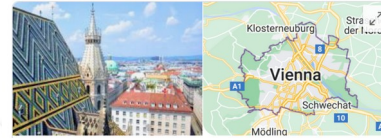
Country: [Austria](#) Elevation: 151 (Lobau) – 542 (Herman...  
 Demyonym(s): [German: Wiener \(m\)](#), [Wien...](#) GDP per capita: € 50,400 (2020)

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### Points of interest

View 20+ more



- cities
- points of interest
- universities etc. ...



# Symbolic AI in Daily Use



Google

Vienna

All Maps News Images Videos More Tools

About 722.000.000 results (0,58 seconds)

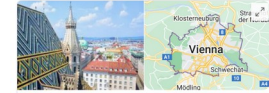
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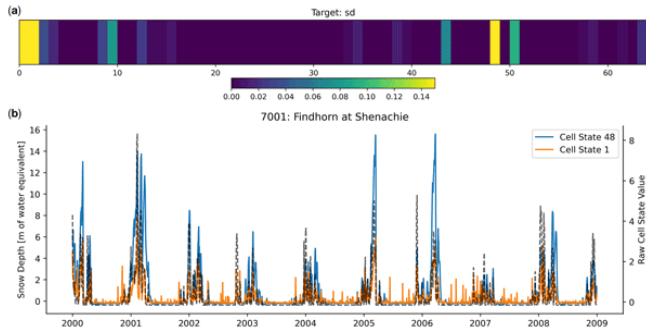
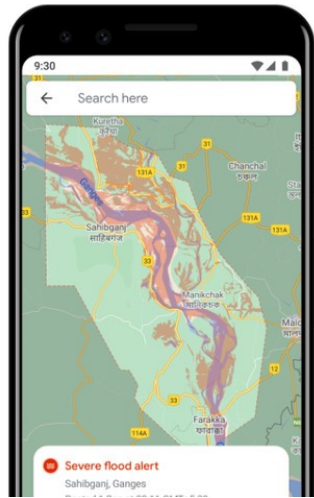
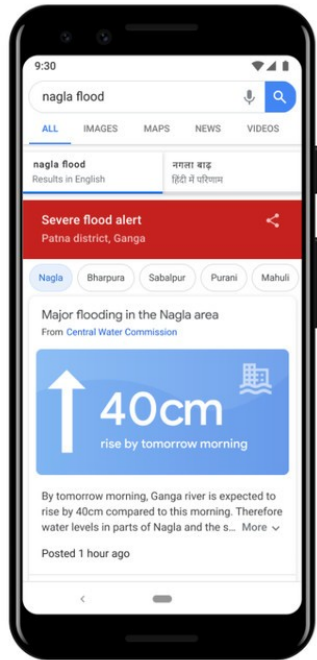
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**nive vier** **TU WIEN** **WU** **UNIVERSITY OF VIENNA**  
University of Vienna Vienna University of Techn... Vienna University of Econo... Medical University of Vienna

Points of interest [View 20+ more](#)  
Schönbr... St. The Belvedere



# Green AI and Climate Change



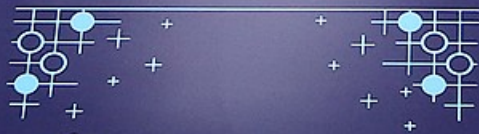
# AlphaGo beats Lee Sedol



AlphaGo



Lee Sedol



Google DeepMind  
Challenge Match

8 - 15 March 2016



# AI for Fusion Control

“Magnetic control of tokamak plasmas through deep reinforcement learning”  
Nature 602, 414–419 (2022)

Uses Long short-term memory (LSTM) and exponential linear unit from Linz.

