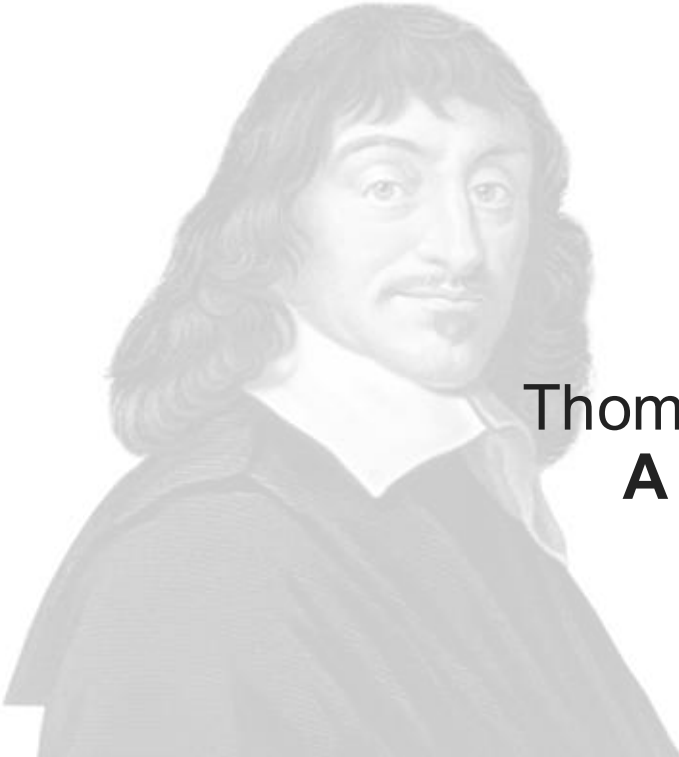


Embodiment in the AI Era

Thomas Hellström

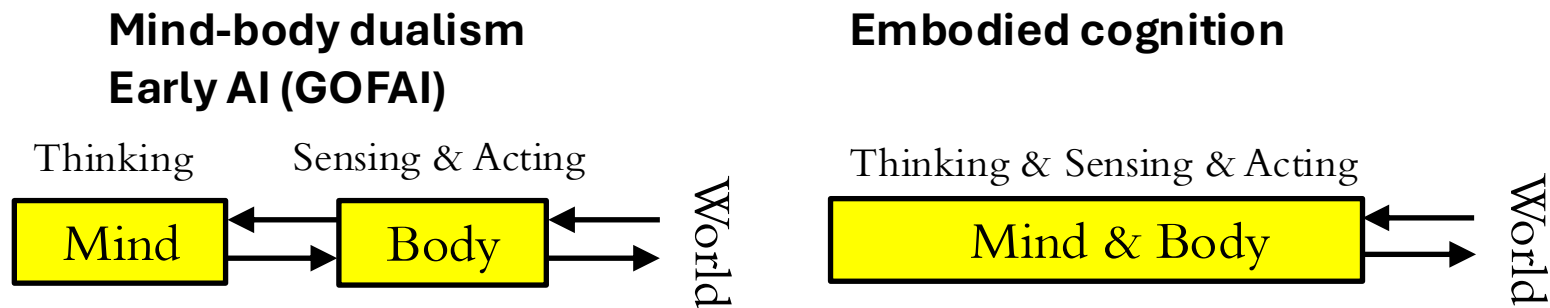
based on

Thomas Hellström, Niclas Kaiser, and Suna Bensch
A Taxonomy of Embodiment in the AI Era
Electronics 2024, 13, 4441



What is Embodiment?

- Has been discussed for millennia
- No conclusion has been reached
- It's about how mind, body, and environment are *intertwined* and how this relates to cognition and intelligence



intelligence emerges in the interaction of an agent with an environment!



Descartes
~1640



McCarthy
1956



Husserl
~1920



Brooks
~1980



Matarić
2006



Smith
2005



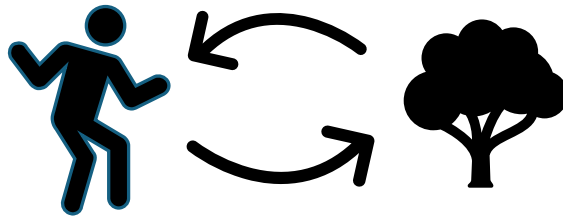
Zuckerberg
~2020

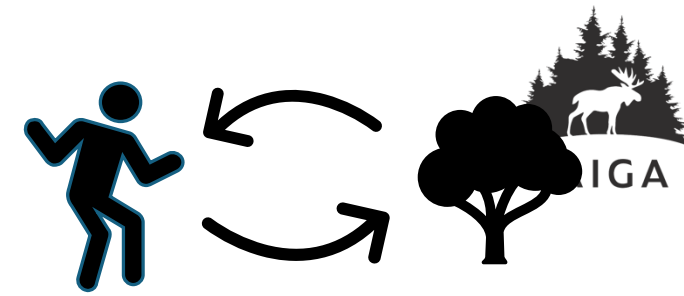
Embodied Cognition



1. We have a body (and it matters).
2. What we sense affect how we act.
Our actions change the environment,
such that what we sense changes.

Sensing, acting, and
thinking are intertwined.





Embodiment in the AI Era

- Historically, embodiment focused on humans
- Then on robots
- Recent development added complexity:
VR, AR, telepresence, metaverse, digital twins, LLMs, ...
- Many types of artifacts can be embodied – and also in virtual environments
- In [1] we introduce a taxonomy that distinguishes between different instances of embodiment in a meaningful way
- New concepts: “mediated embodiment”, “embodiment by proxy”, “off-line embodiment”
- Why is embodiment important?
 - It is a central concept in AI and Cognitive Science
 - Embodiment is connected to power and societal effects!

What is a taxonomy?

A way to characterize and classify instances of, for example, footwear:

	Category	Material	Price	Color
	Shoe	Leather	\$\$	Brown
	Boot	Rubber	\$	Blue
	Shoe	Plastic	\$	Red

or instances of embodiment ...

How do we characterize embodiment?

1. Who/what is embodied? (**Embodied agent**)
2. Who/what does the sensing and acting? (**Mediator**)
3. In which **Environment** does sensing and acting take place?
4. How strong is the capability to sense and act (“**degree of body**“)?
5. How strong is the coupling between sensing and acting (“**degree of intertwining**“)?

These are the five dimensions of our proposed taxonomy of embodiment.

Embodied humans

Who is embodied?

Who is sensing and acting?

Where does sensing and acting take place?

“Physically embodied”

“Virtually embodied”

“Physically AND
virtually embodied”

Embodied agent	Mediator	Environment	Degree of body and intertwining
Human 	-	The physical world	
Human with AR glasses 	-	The physical world	
Human operating a telepresence robot 	Telepresence robot 	The physical world	
Human 	Avatar 	A Metaverse world	
Human with VR glasses 	Avatar 	A Metaverse world	
Human with Spatial Computing glasses 	Avatar	Both the physical world and a virtual world	

How much sensing and acting, and how much are they intertwined?

Virtual embodiment

Mind-body dualism

The soul of Descartes

The body of Descartes



The physical world

Embodied robots and other artifacts

Embodied agent	Mediator	Environment	Degree of body and intertwining
Traditional Industrial Robot 	-	The physical world	■
Early AI robot (Shakey) 	-	The physical world	■■■■
Self-driving car 	-	The physical world	■■■
Smart building 	-	The physical world	■■■

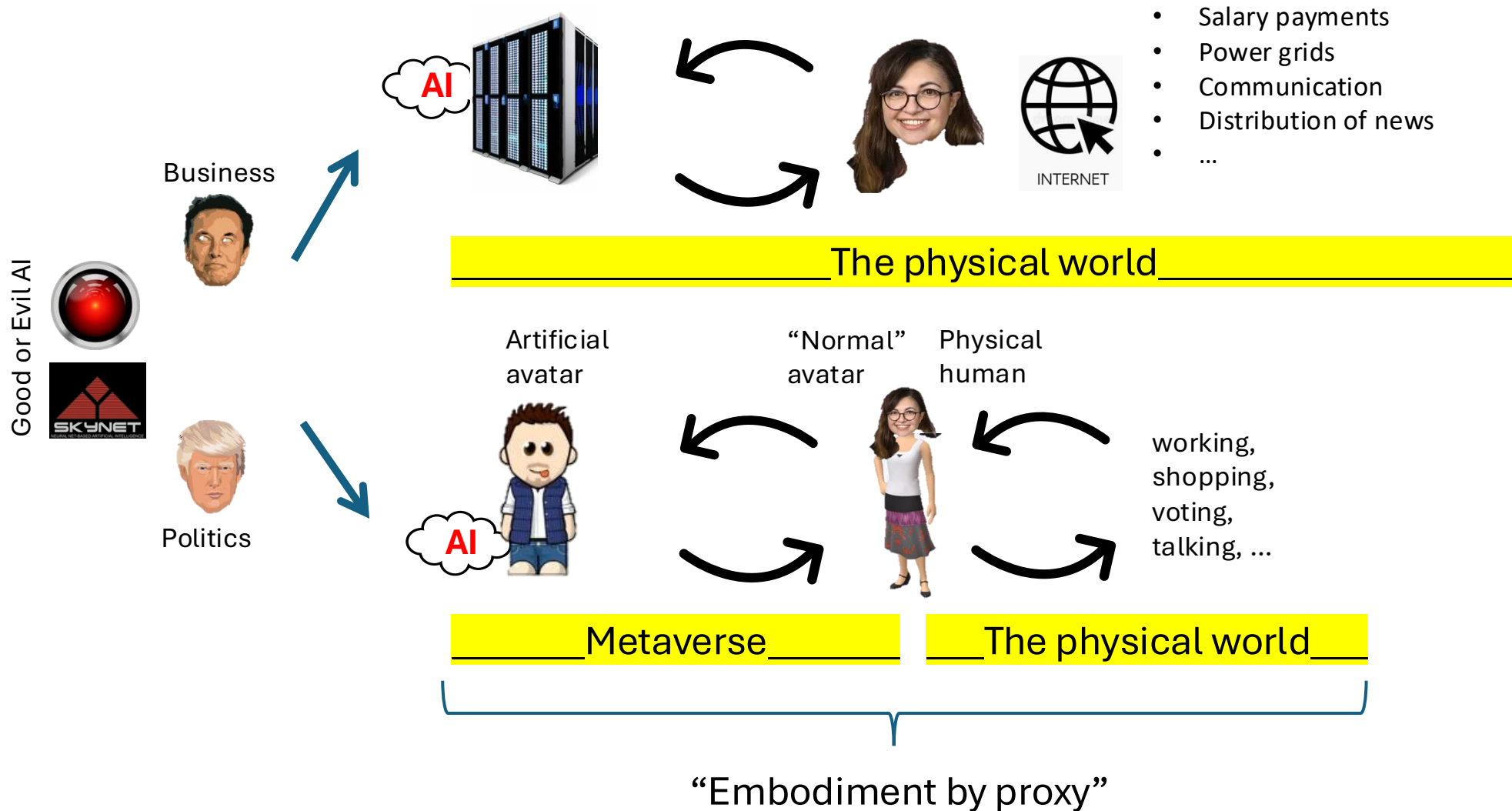
Embodied computer programs

Embodied agent	Mediator	Environment	Degree of body and intertwining
MS-DOS operating system 	IBM PC 	The physical world	
ChatGPT 	Iphone 	The physical world	 *
Chatbot	Smart speaker 	The physical world	 *
Software agent	-	The Internet	
AI program 	Artificial avatar 	A Metaverse world	
AI program 	Super Computer 	The physical world	

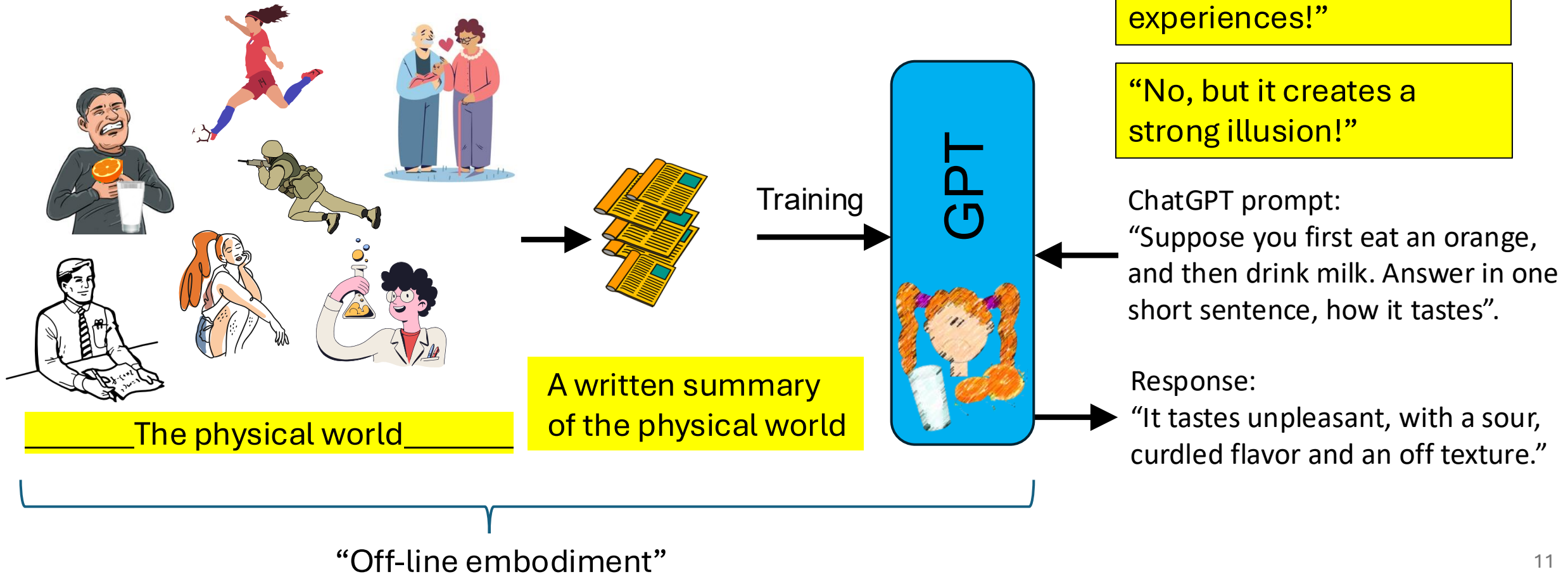
An avatar controlled by a program (a.k.a. “bot”)



Embodiment by proxy



LLMs and Off-line embodiment



"LLMs are off-line!"

"LLMs can't express first-person sensory experiences!"

"No, but it creates a strong illusion!"

The State and Status of Embodiment



Physical embodiment in declining

- Google and OpenAI have sold off their robotics companies
- Ford and Volkswagen shut down joint development of self-driving cars in 2022
- EU's frame program: "Robotics" is now part of "AI, data and robotics"

Virtual embodiment is flourishing (LLMs, metaverse, VR, "Embodied AI"...)

- Much easier! Circumvents the noisy, dynamic physical world, and inaccurate sensors
- Virtual solutions "scale" commercially

The virtual will become more physical

- IoT, computers sensing and controlling the physical world
- Decision support systems → decision systems
- Embodiment by proxy

