From Sensing to Acting

Can Pervasive Computing Change the World?

by M. Midzan, M. Schref

Further potential for pervasive computing lies in developing the "*acting*" aspect.

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Introduction

Pervasive Computing so far:

- integrating computing into daily life & physical world
- progress in "**sensing**" and "**thinking**"

Next Steps:

- developing "**acting**": allow computers to adapt and react to changes
- exploiting **AI & ML** to make use of collected data

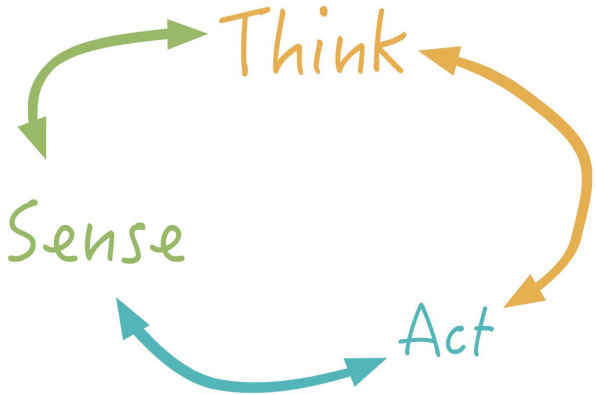

Figure: Sense-Think-Act Paradigm [1]

Reference: [1] Bardram, J.E. (2022)

There is a need for novel actuator technology to act on the physical world.

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From Sensing to Acting

Actuator Hardware and Technology:

- influence and act on the physical world
- develop **novel** technologies
- creatively exploit **existing** technologies
- emerging technologies, e.g. artificial pancreas

Operating Systems and Programming Frameworks:

- **Challenge:** link sensing, analysis and actuation together
- new programming abstractions for the full STA paradigm

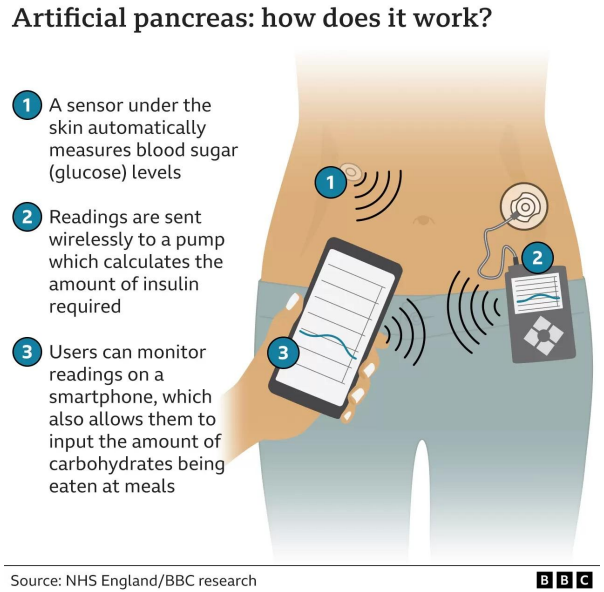

Figure: Artificial pancreas: How does it work? [5]

Reference: [1] Bardram, J.E. (2022), [2] Walsh, F. (2022)

AI & ML may accelerate the development of "*acting*" in pervasive computing.

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AI & ML Models

Generally [1]:

- used for **analyzing and understanding data** in pervasive computing
- huge **potential for many application fields**

Use Case Mental Health [2]:

- recommendation technology **predicting impact of activities on mood**
- ➔ potential to **improve well-being** by **suggesting healthy activities**

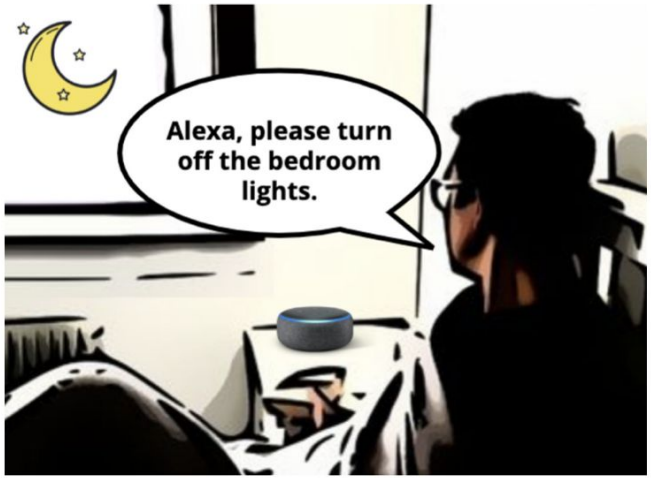

Figure: Conversational agent technology used for both home automation and assessment of mental health [4]

Reference: [1] Bardram, J.E. (2022), [3] Rohani et al. (2021), [4] Maharajan et al. (2019)

New AI models will bring disruptive and yet unpredictable changes to many fields.

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Foundation models

- AI models trained with more than 10^{12} parameters
- flexible, used as **foundation** for innovative tools
- emerging due to increased computing power

Capabilities:

- generation of **human-like text**, engaging in **conversations, creative writing**
- **coding** (generation & improvement)
- **image generation**
- music **composition**
- **control of machines**

and many more

Reference: [5] The Economist, 2022

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"The models have unforeseeable capabilities …

*with potential for **significant economic impact and disruption***

… and Graphcore is developing a computer called "Good" … Good is being built to run AI models with 500 trillion parameters …" [5]

Reference: [5] The Economist, 2022

The “*acting*” aspect may be enhanced by considering all senses…

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User Interfaces & User Experience [1]

Most common:

- interactive touch screens
- vibration
- sound

Emerging:

- Intelligent Conversational agents (Apple HomePod/Siri, Amazon Alexa)
- Lightweight smart glasses (Google glasses)
- gesture recognition
- autonomous robots etc.

Reference: [1] Bardram, J.E. (2022)

… and facilitating AI tools from foundational models

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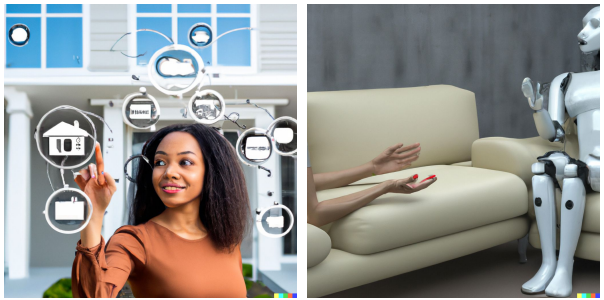
May soon be reality:

New interfaces merged with AI tools from foundational models



Images: futuristic robots/systems created with DALL-E 2 [6]

Reference: [1] Bardram, J.E. (2022), [6]: OpenAI (2023)

Pervasive Computing will become more interdisciplinary and autonomous.

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Topics and Challenges in Pervasive Computing Research

Innovative Actuator Technology:

- **application-specific** technologies, e.g., in home automation or healthcare
- **generic** technologies, e.g, general-purpose recommender technology
- Pervasive Computing research will be even more **interdisciplinary**
- **Robotics** and **Autonomous Systems** will become increasingly relevant

Safety Issues:

- ***sensing*** ↔ ***privacy*** ***actuation*** ↔ ***(human) safety***

- Actions of a computer may be **irreversible**, e.g., ICD
- strict **validation** and regulatory **certifications** for systems

Reference: [1] Bardram, J.E. (2022)

Merged with user centric development, system autonomy will further increase.

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Further Topics and Challenges

Levels of System Autonomy:

- degree of system independence and human involvement
- Human-Computer-Interaction (HCI) research more relevant
- user autonomy versus tool autonomy

User Involvement:

- communicating with the user
- contacting the user
- understanding the user's actions and vice versa

Reference: [1] Bardram, J.E. (2022)

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Conclusion

- **sensing** and **thinking well developed**
- **acting** has to be further developed to "*change the world" by **actively assisting humans***
- The acting aspect is on the rise with new applications (e.g. healthcare)

How the transition may be successful:

- employing and merging new **User Interfaces, AI & ML** and **autonomous systems**/robotics
- by utilizing **foundational AI models**

Issues:

- **Safety** and **biased AI**

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References

[1] Bardram, J. E. (2022). From Sensing to Acting—Can Pervasive Computing Change the World?. IEEE Pervasive Computing, 21(3), 17-23.

[2] Walsh, F. (2022). Artificial pancreas to revolutionise diabetes care in England. Accessed on January 4th from: https://www.bbc.com/news/health-60133358

[3] D. A. Rohani, et al. (2021). “Recommending activities for mental health and well-being: Insights from two user studies,”IEEE Trans. Emerg. Topics Comput., vol. 9, no. 3, pp. 1183–1193.

[4] R. Maharjan, et al. (2019), ““Hear me out”: Smart speaker based conversational agentto monitor symptoms in mental health,” in Adjunct Proc. ACM Int. Joint Conf. Pervasive Ubiquitous Comput. Proc. ACM Int. Symp. Wearable Comput., 2019, pp. 929–933.

[5] The Economist (2022). Huge “foundation models” are turbo-charging AI progress. Accessed on January 2nd from: https://www.economist.com/interactive/briefing/2022/06/11/huge-foundation-models-are-turbo-charging-ai-progress

[6]: OpenAI (2023). DALL-E 2 text to image generator, from: https://labs.openai.com/e/p2LfiFr48AKJ5MRUo7OvO73E

Backup: Examples of (foundational) AI models

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Large Language Models (LLM)

- AI trained on large text datasets
- generates human-like text
- translation, question answering, code generation
- Billions of parameters capturing complexity of natural language (“*large*”)
- Examples: (Chat)GPT (OpenAI), BERT (Google), RoBERTa (HuggingFace)

Text to Image Models

- trained with large amount of images and text from web
- generates image based on natural language description
- developed in 2010, can generate images similar to real photos since 2022
- examples: DALL-E 2 (OpenAI), Imagen (Google), Stable Diffusion (StabilityAI)