ONWARD!
PAPERS

HPI

Talking to Objects in Natural Language

Toward Semantic Tools for Exploratory Programming

Christoph Thiede, Marcel Taeumel,
Lukas Böhme, Robert Hirschfeld

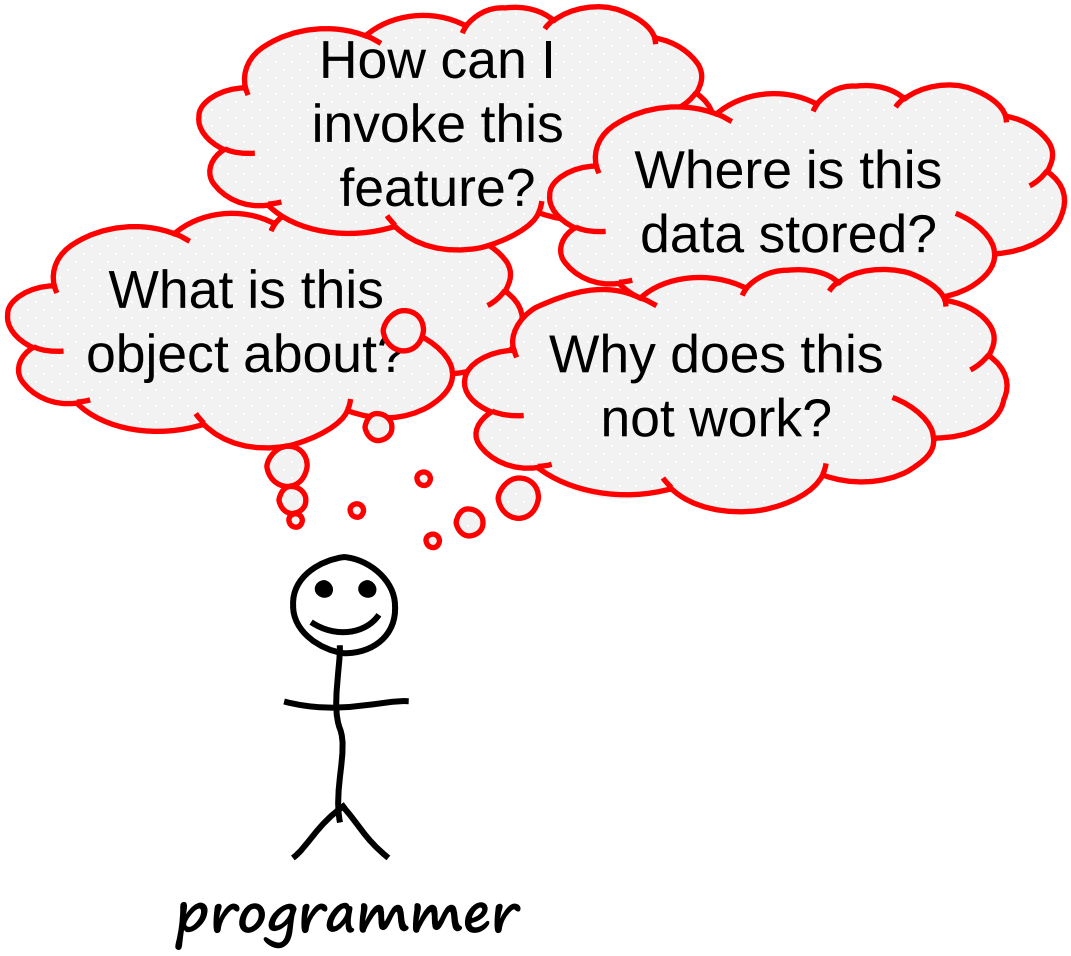
Software Architecture Group

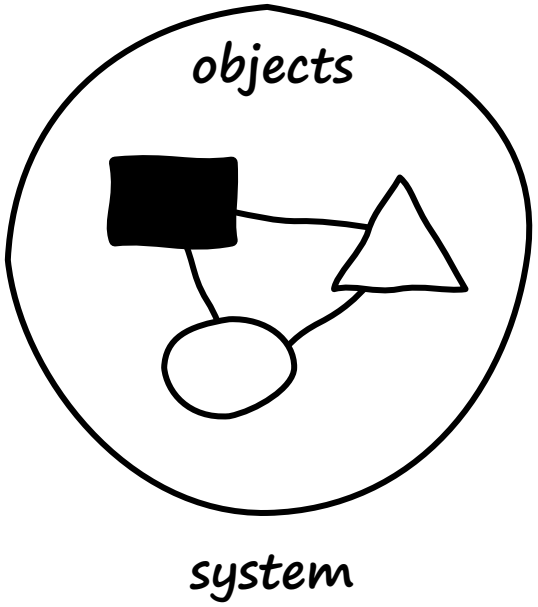
Hasso Plattner Institute, Potsdam, Germany

hpi.uni-potsdam.de/swa

Motivation

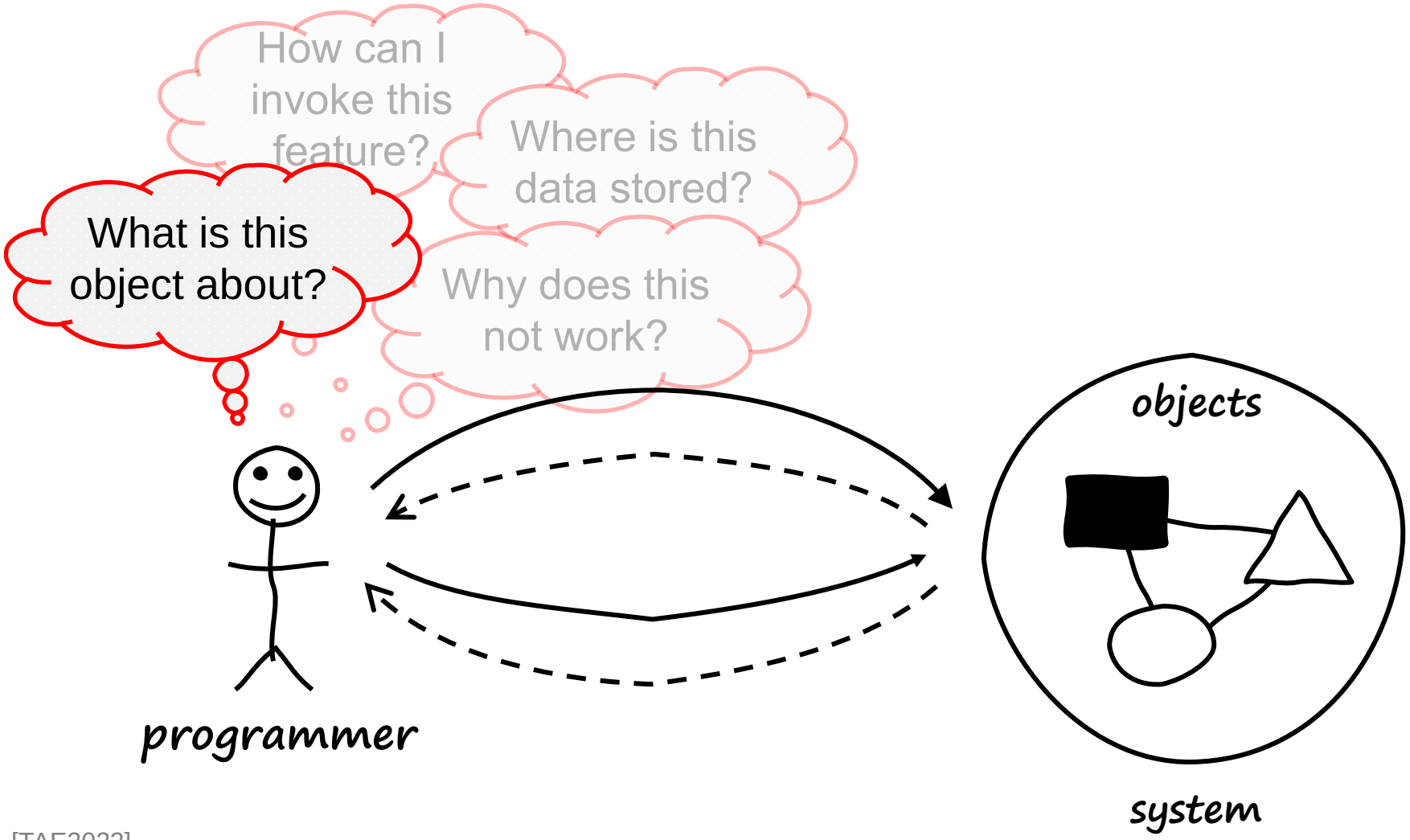
Motivation





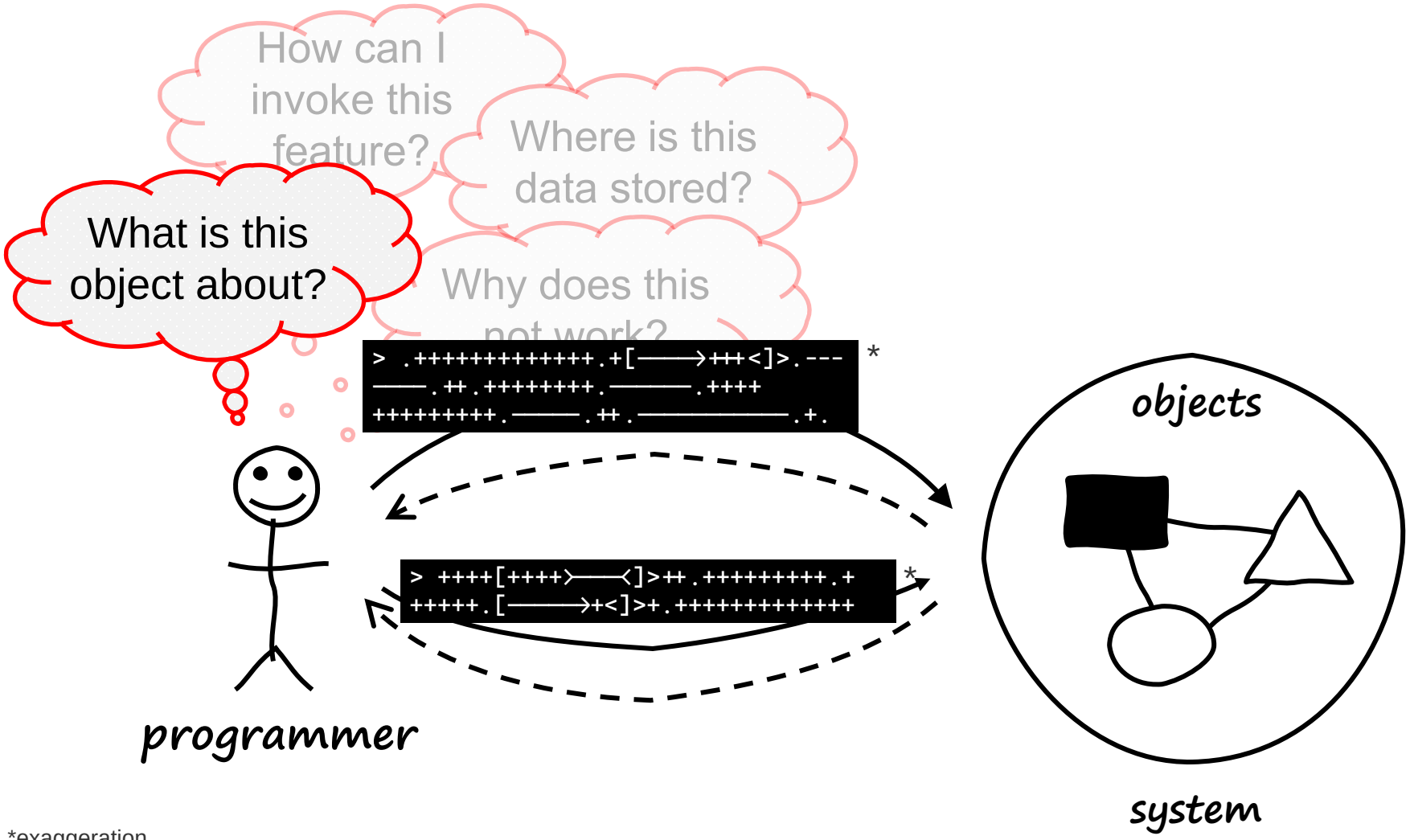
[SAN1988,REI2019]

Motivation



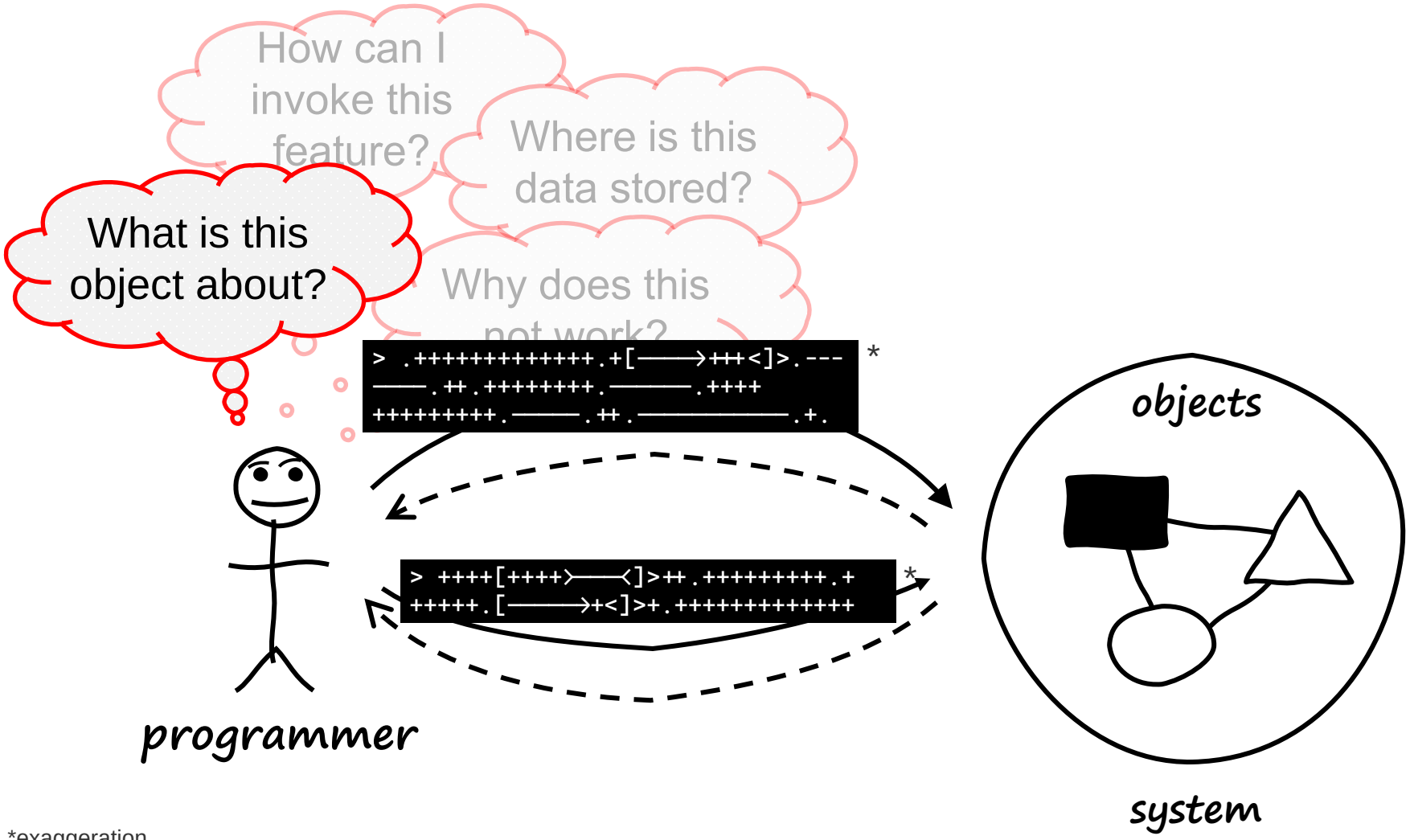
[TAE2022]

Motivation



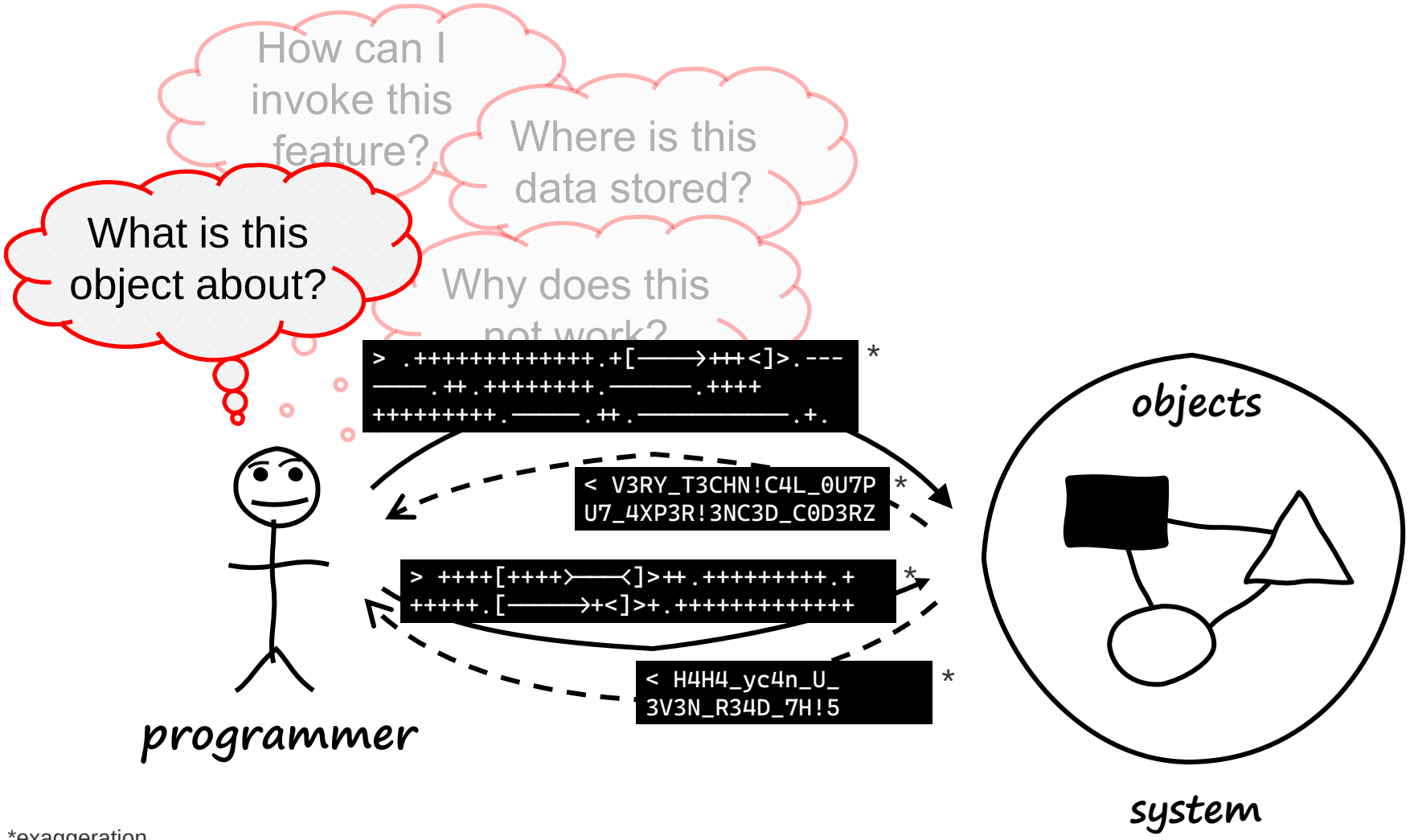
*exaggeration

Motivation



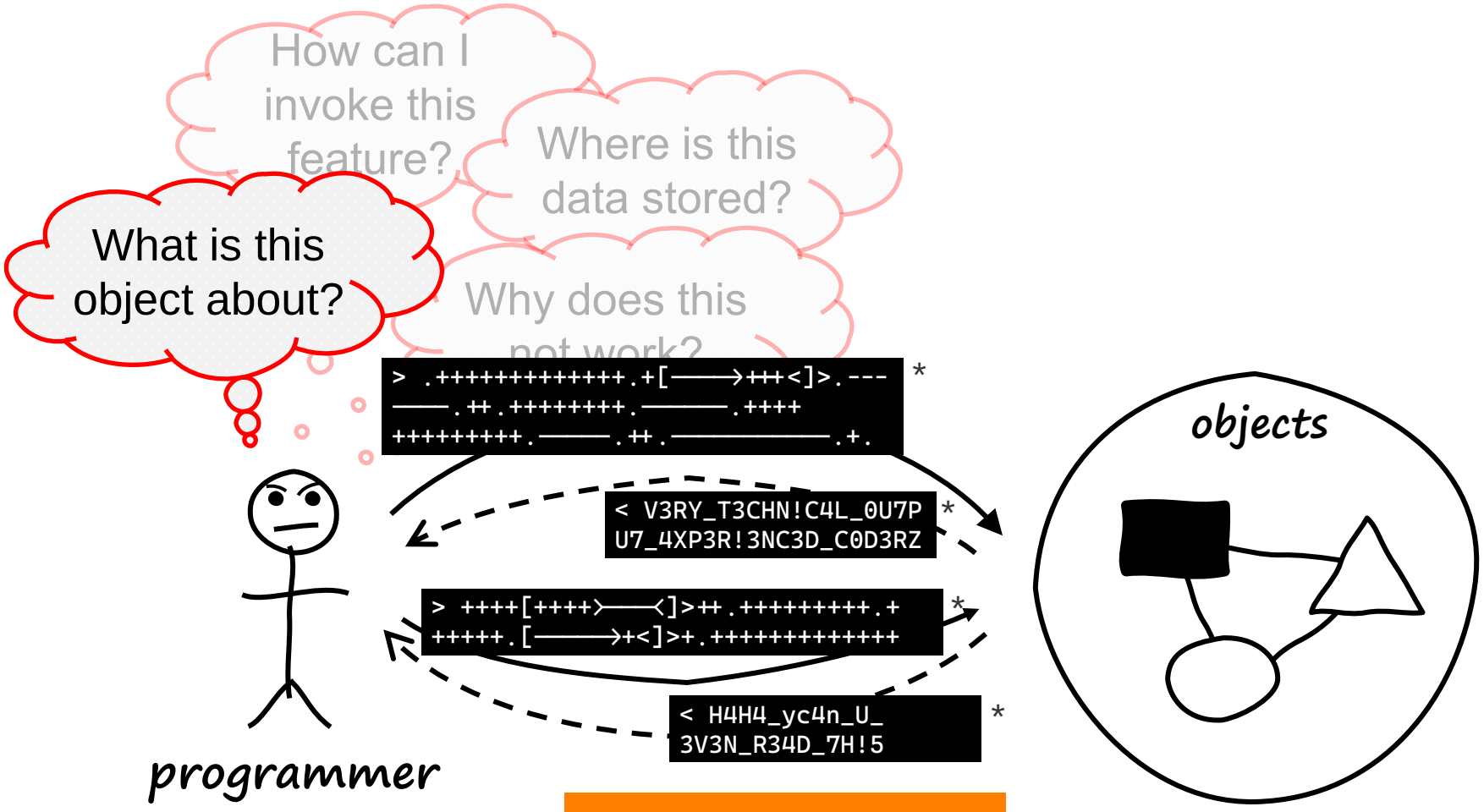
*exaggeration

Motivation



*exaggeration

Motivation

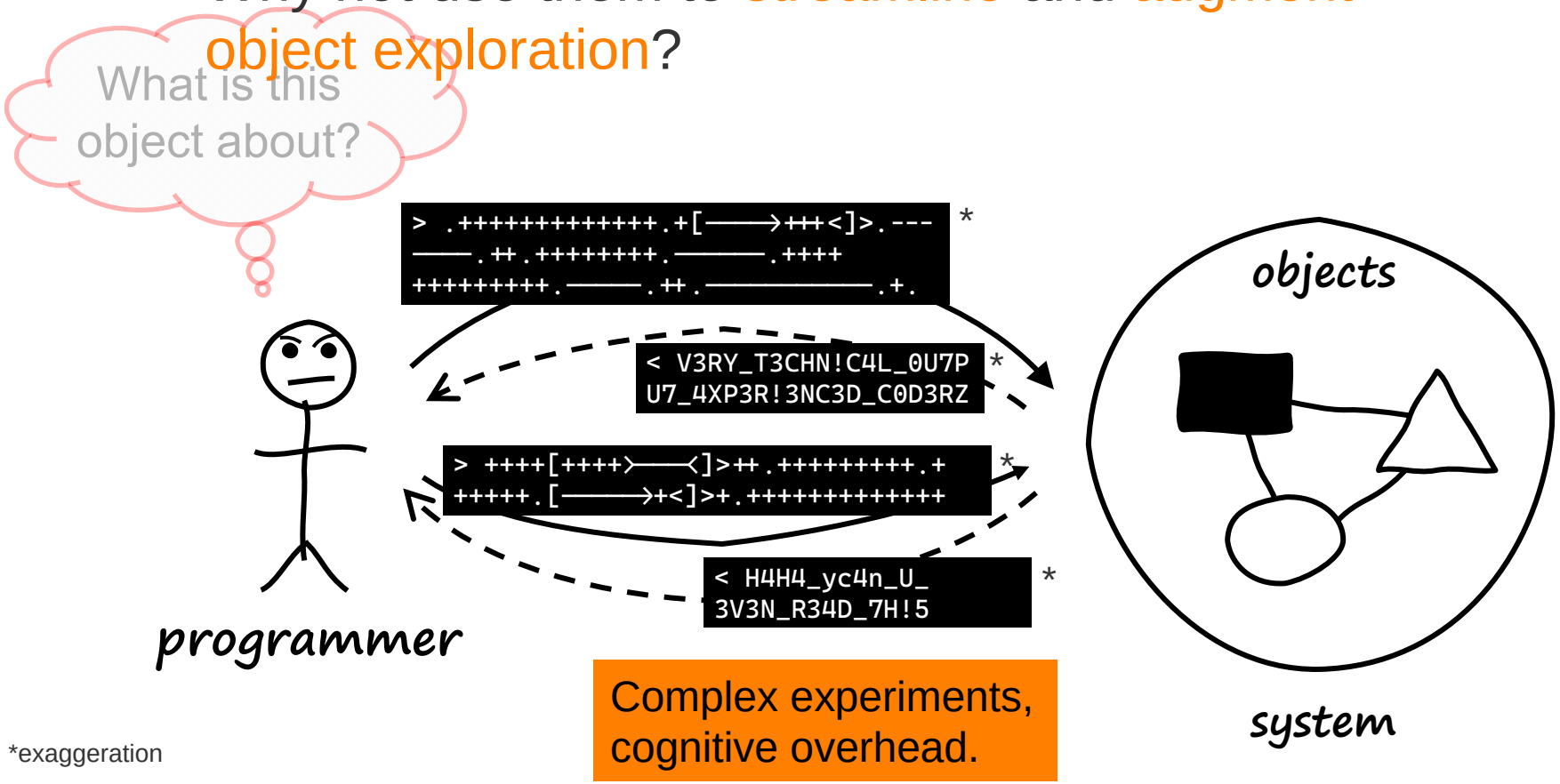


Complex experiments, cognitive overhead.

*exaggeration

Idea

- Generative AI agents already support programmers at different comprehension and interaction tasks ...
- Why not use them to streamline and augment object exploration?

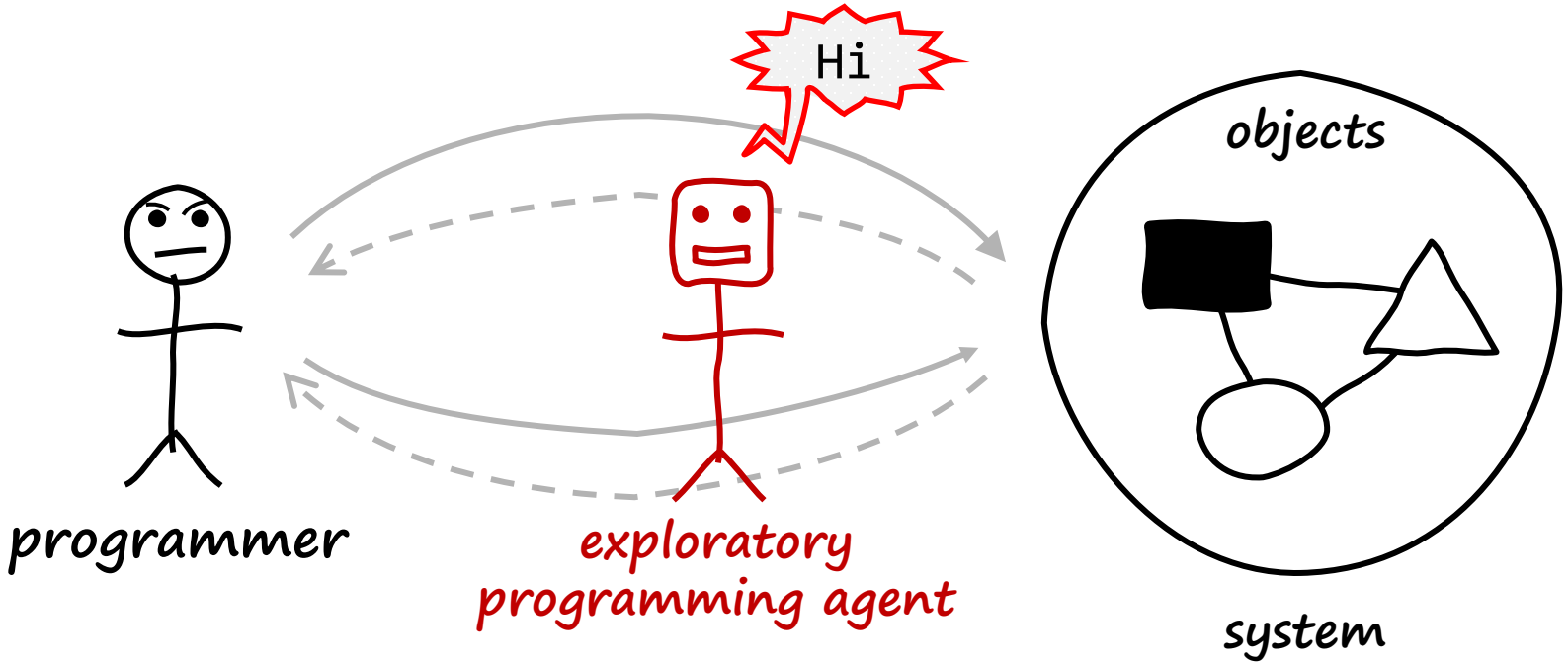


Complex experiments, cognitive overhead.

*exaggeration

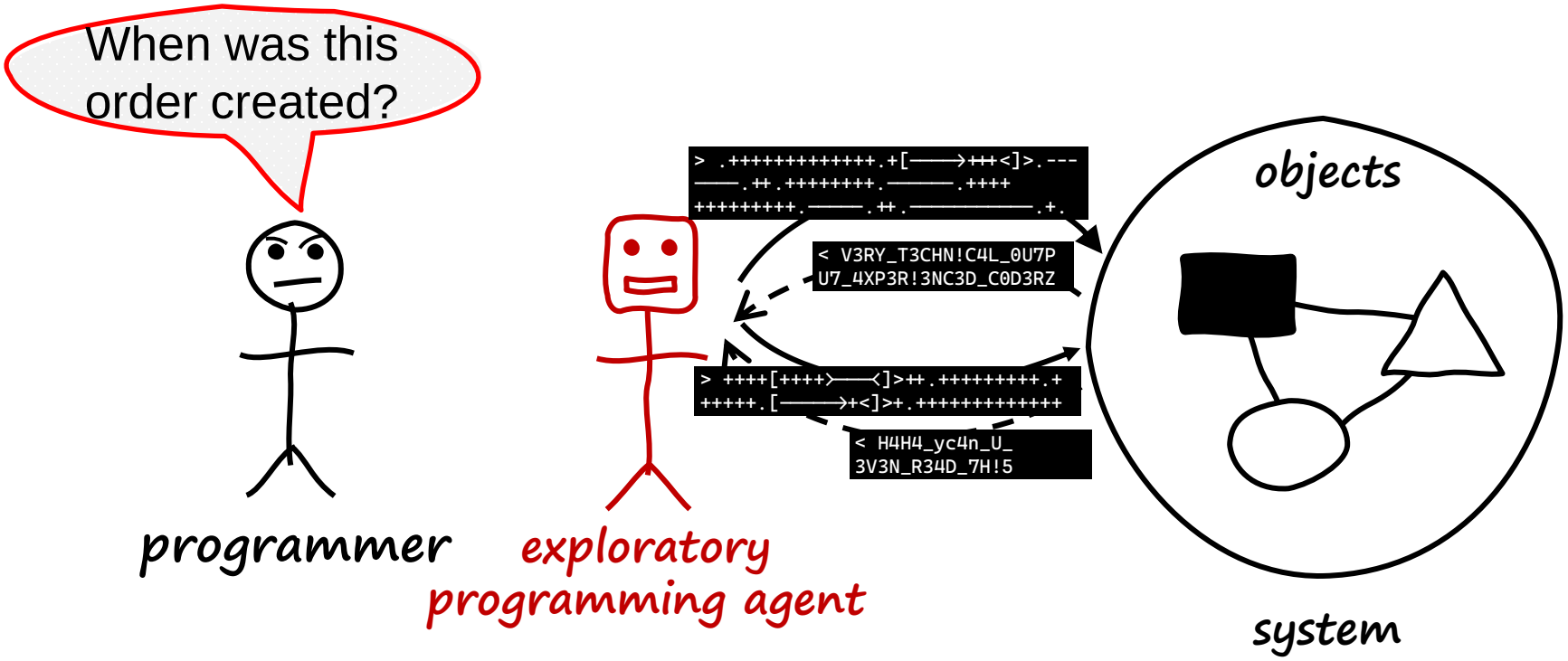
Idea

- Generative AI agents already support programmers at different comprehension and interaction tasks ...
- Why not use them to streamline and augment object exploration?



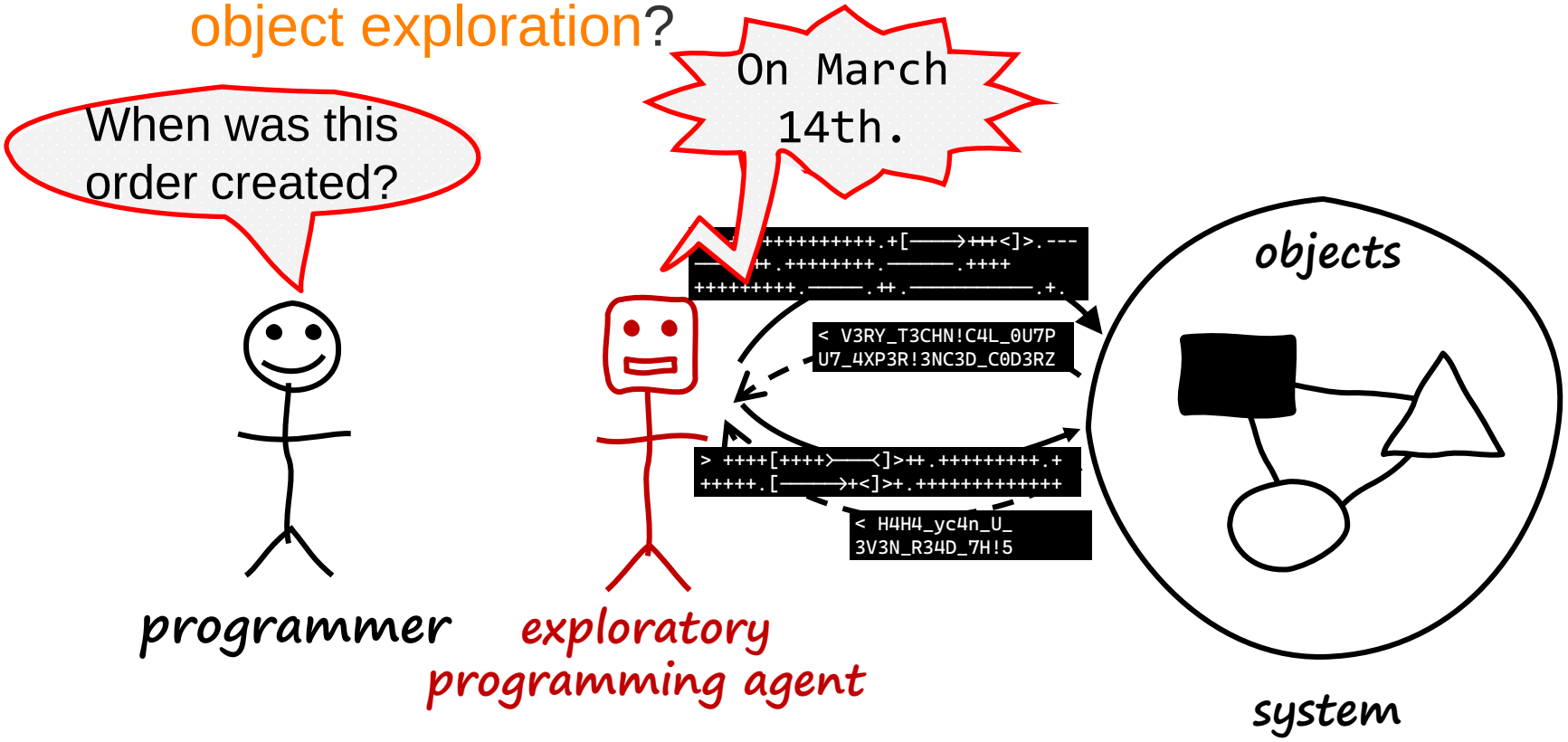
Idea

- Generative AI agents already support programmers at different comprehension and interaction tasks ...
- Why not use them to streamline and augment object exploration?



Idea

- Generative AI agents already support programmers at different comprehension and interaction tasks ...
- Why not use them to streamline and augment object exploration?



Research Question

How can we support exploratory programming through semantic object interfaces that enable contextual, natural-language conversations with or about objects?

Contributions

Semantic object interfaces framework

Prototype
for Squeak/Smalltalk, using GPT-4o

Evaluation
from our experience

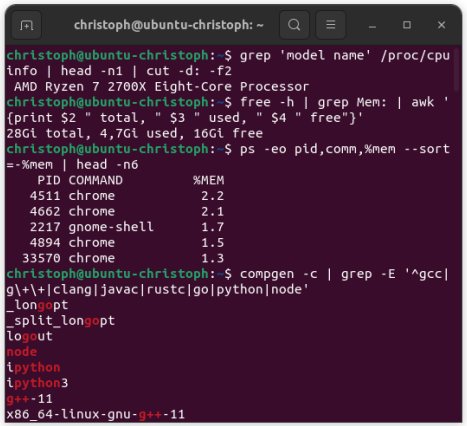
Background

Background: Exploratory Programming

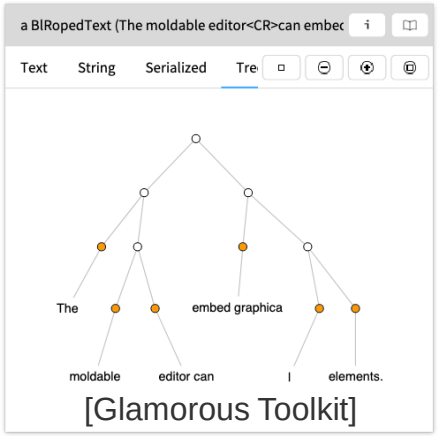
- Exploratory programmers understand problems and systems iteratively [SAN1988,REI2019]
- They work like researchers: they formulate questions, conduct experiments, and evaluate results
- They conduct vivid and extensive conversations with systems through many small experiments [TAE2022]

Background: Exploratory Programming Systems

- Liveness for short feedback cycles [SAN1988,TAN2013]

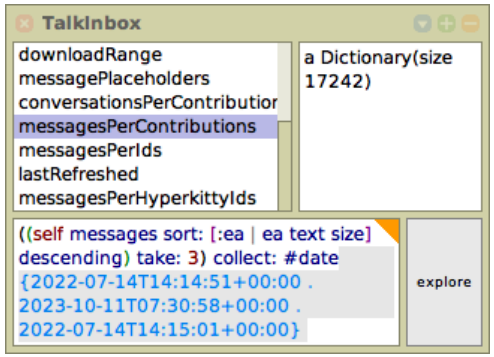


[Bash]

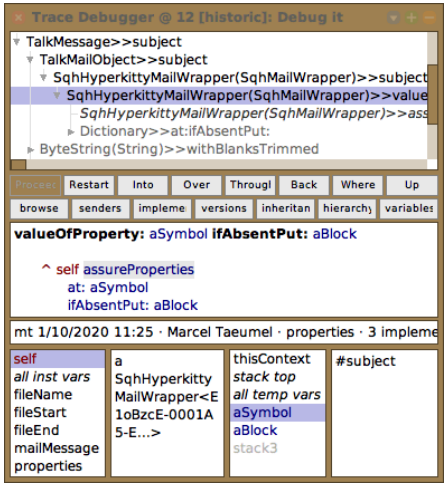


[Glamorous Toolkit]

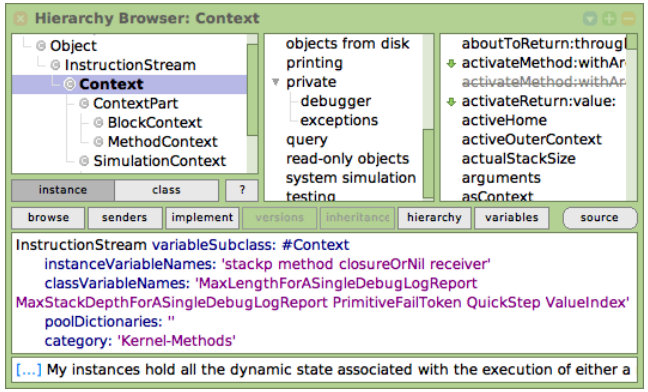
[Jupyter]



[Squeak]

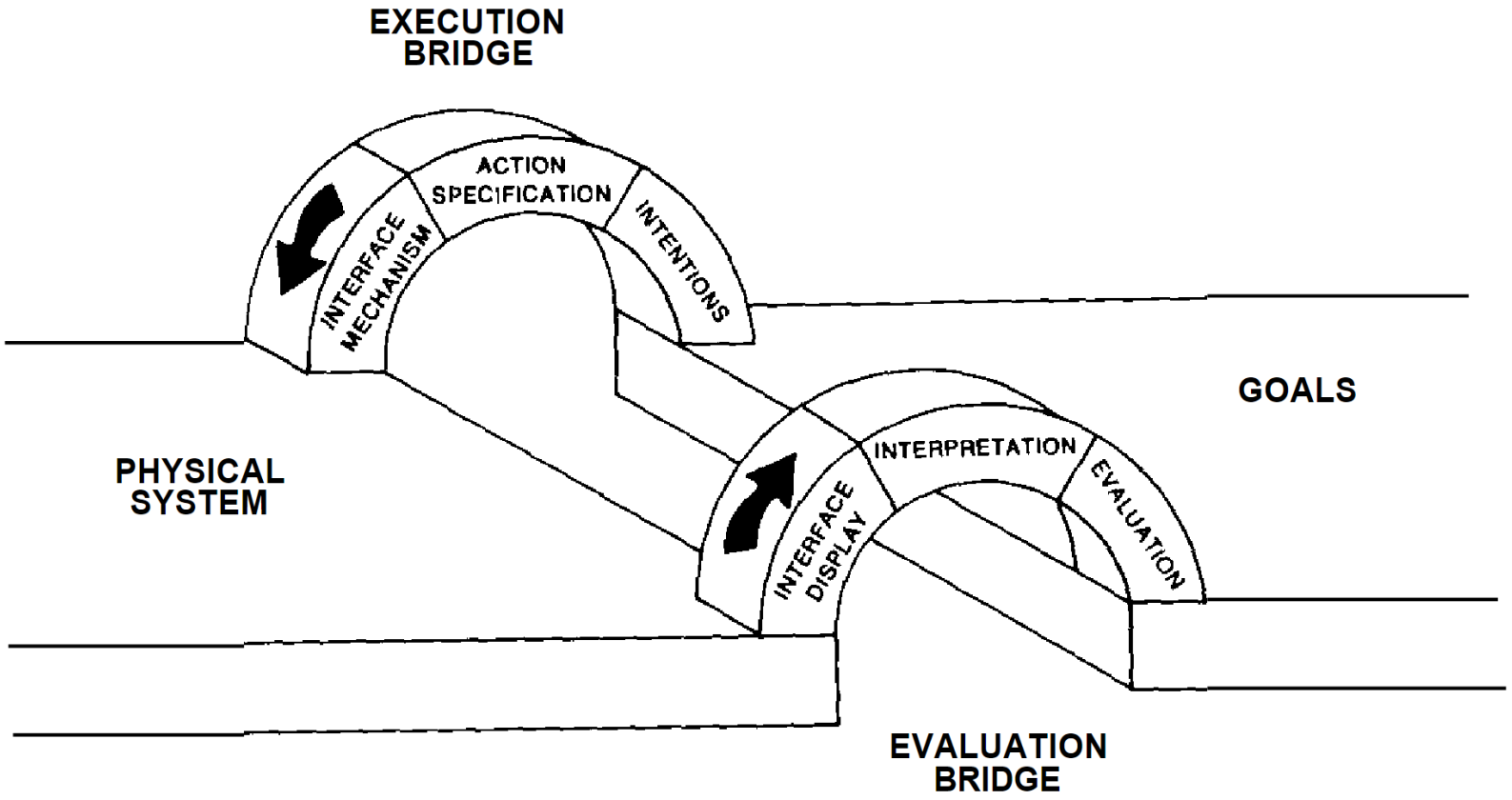


[TraceDebugger]



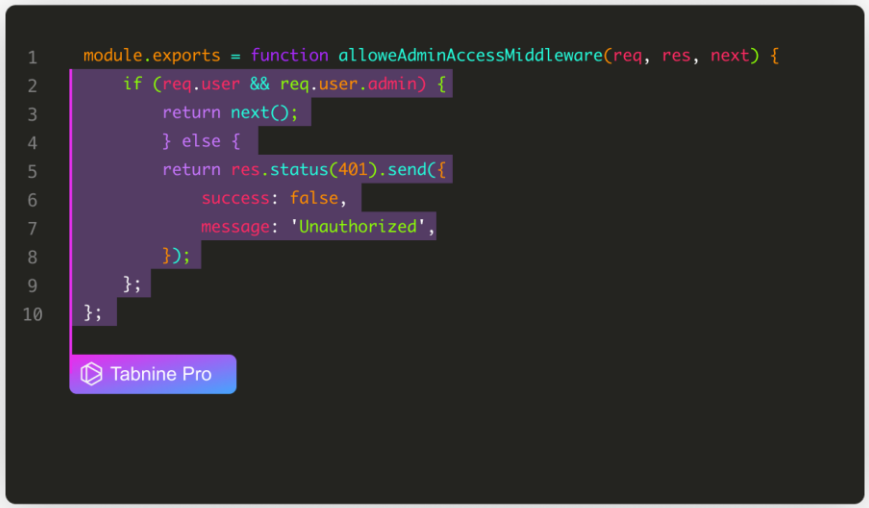
[Squeak]

Background: Two Gulfs of HCI

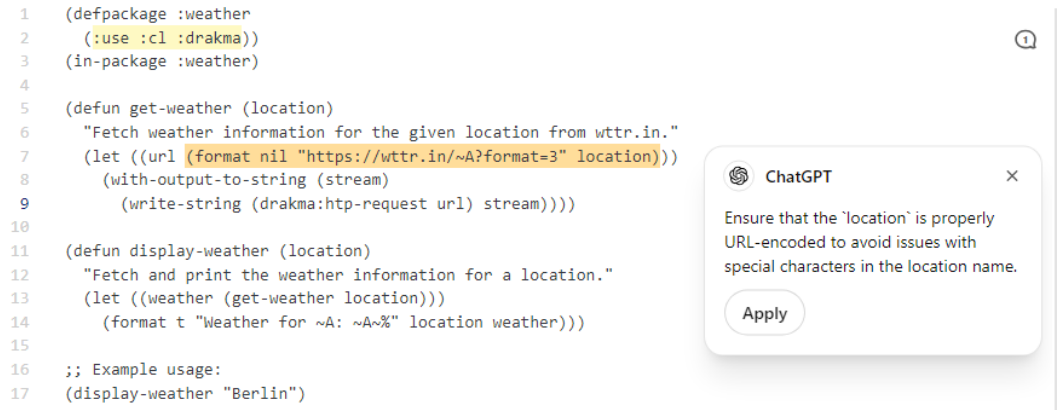


[NOR1986]

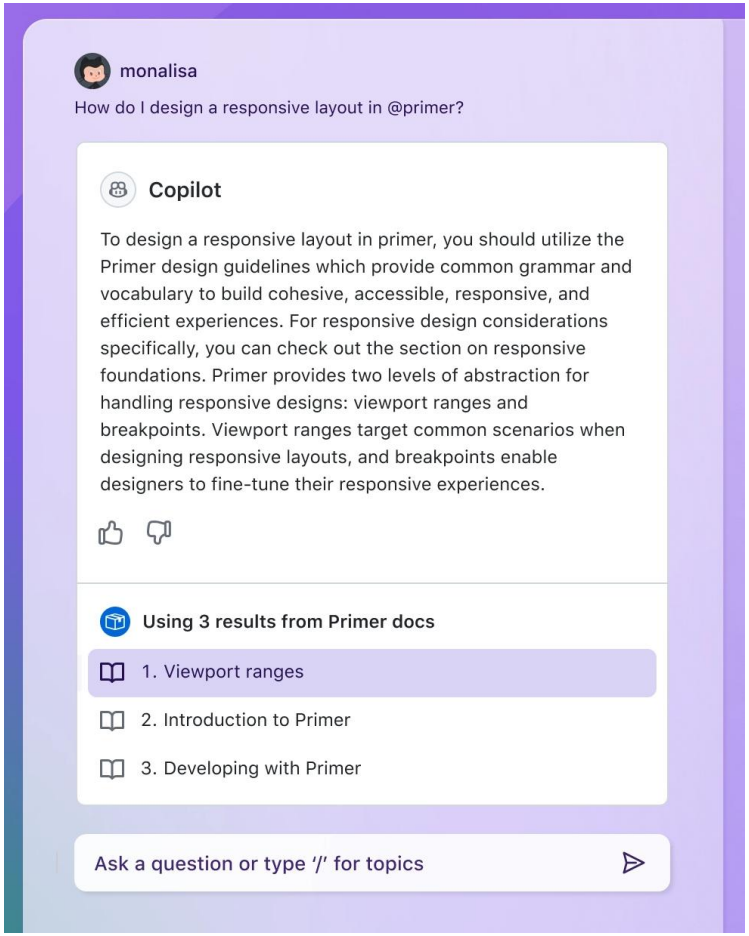
Background: Generative AI



[Tabnine]



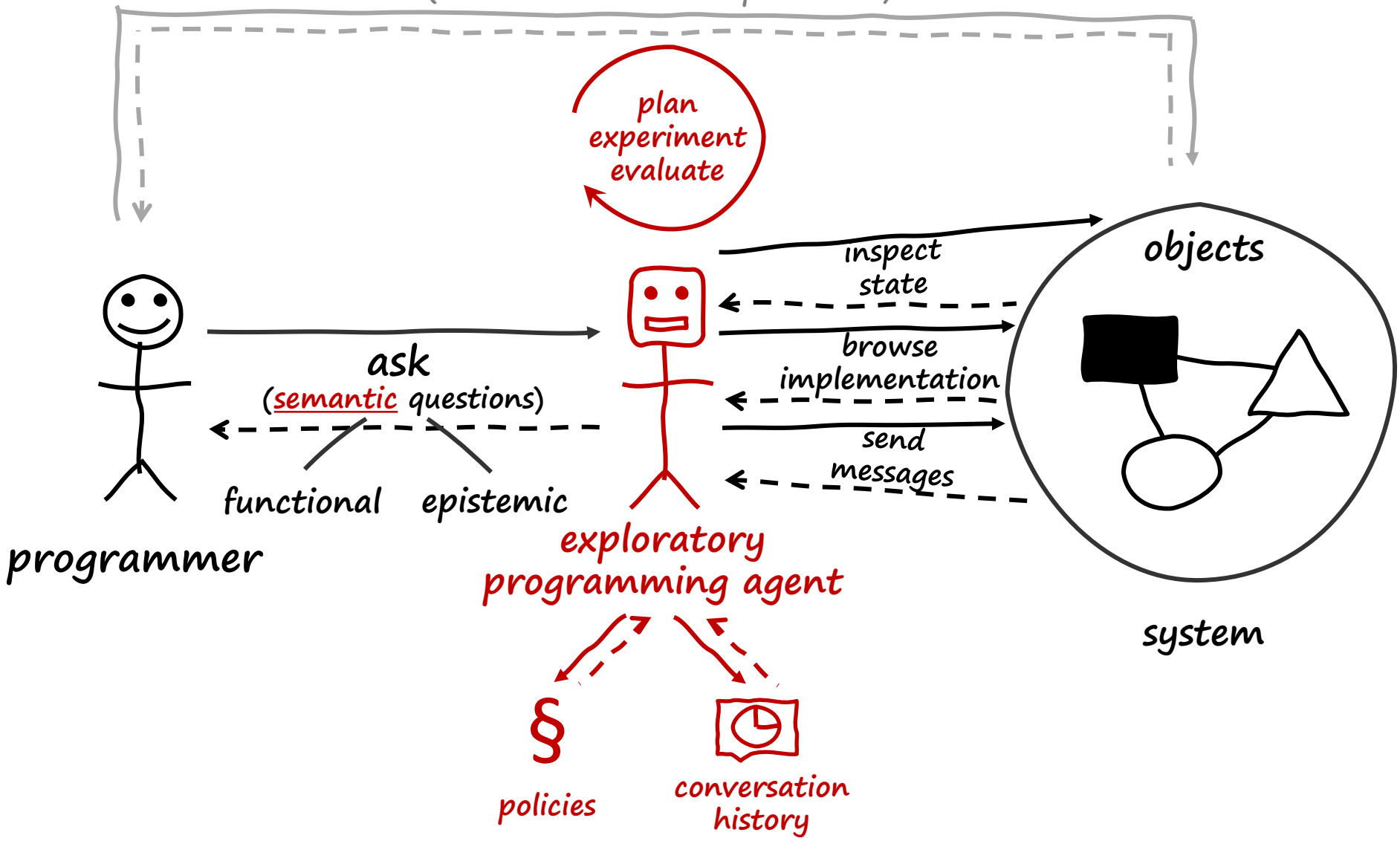
[ChatGPT]



[GitHub Copilot]

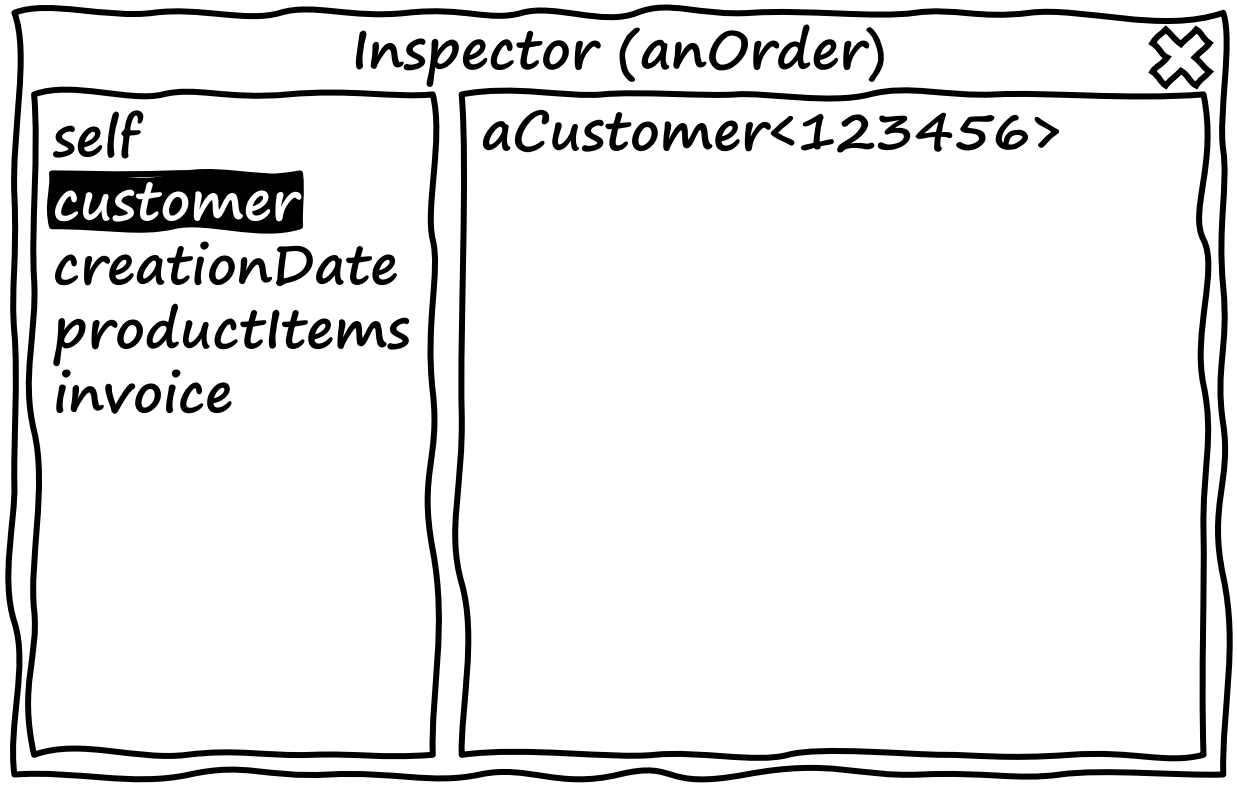
Approach: Semantic Object Interfaces

(traditional manual experiments)

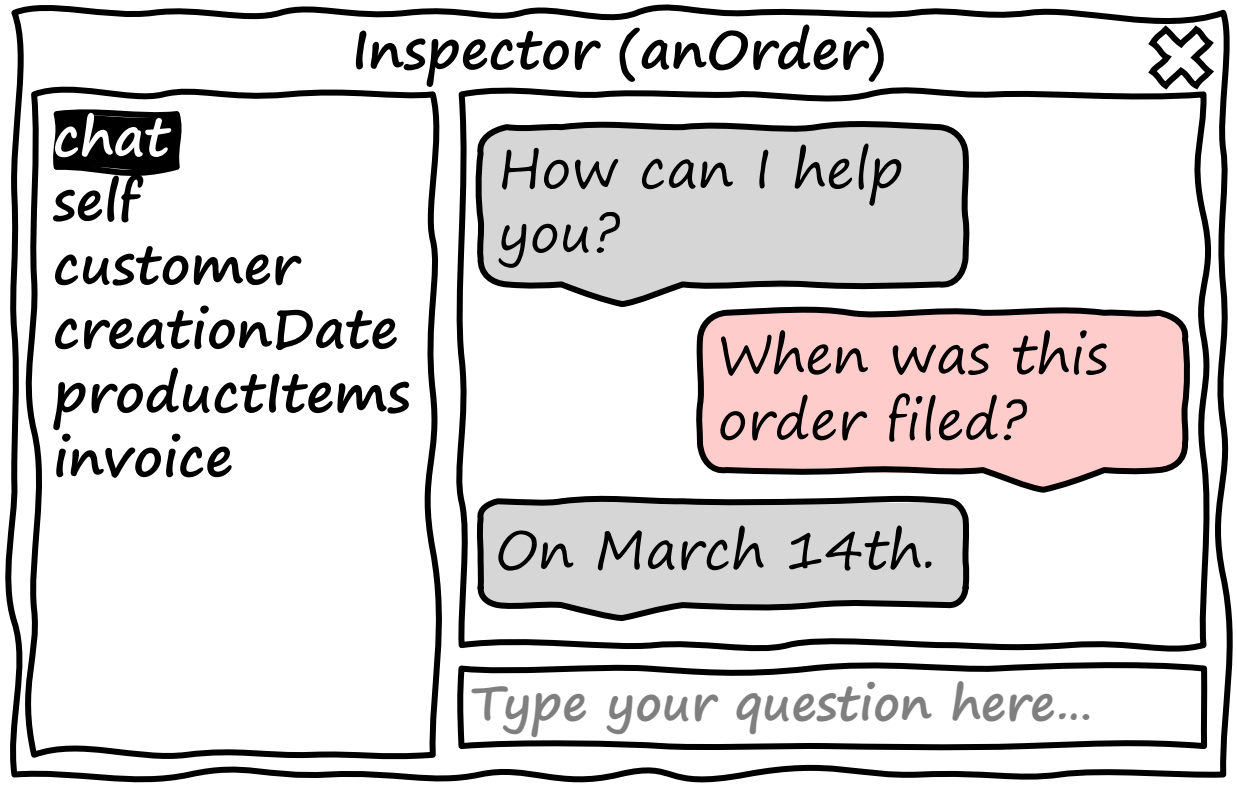


Integration into Programming System

Integration: Conversation Mode for Object Inspection Tools



Integration: Conversation Mode for Object Inspection Tools



Integration: Semantic Messaging for Scripts

- Traditional scripting:
  - `aProduct customer lastName.`
  - `(aProduct orderItems detectMax: #quantity) product.`
- Scripting with semantic messages:
  - `aProduct orderItems mostOftenBoughtOne.`
  - `aProduct mostPopularArticle.`
  - `aProduct numberOfSalesTo: aCustomer.`
  - `aProduct countSalesFrom: '2023Q3' to: '2023Q4'.`

Building an Exploratory Programming Agent

GPT-4o

Building an Exploratory Programming Agent: Implementing Policies through Prompts

HEADER

Exploratory programming agent

System: You are an exploratory programming agent...
- *identity*

System: You can call the following functions...
- *interface description*

System: To solve a task, you should...
- *rules and traits for problem solving*

Conversation mode (optional)

System: You are an object...
- *object identity*

System: Keep your answers brief...
- *output format*

Semantic messaging (optional)

System: You must call the `evalAndReturn` function...

System: Format the return value as...
- *output format*

Bootstrapping the exploration

System: This object represents...
- *hardcoded semantic context*

Assistant: To understand this object, I will first...
- *zero-shot chain-of-thought*

Assistant: `eval("self printString")`

Result: `an Object(12345)`

Assistant: `eval("self allInstVarNames")`

Result: `#('foo' 'bar')`
- *initial object context*

BODY

User: What does this object...?
- *user question*

Building an Exploratory Programming Agent: System Interfaces for Experiments

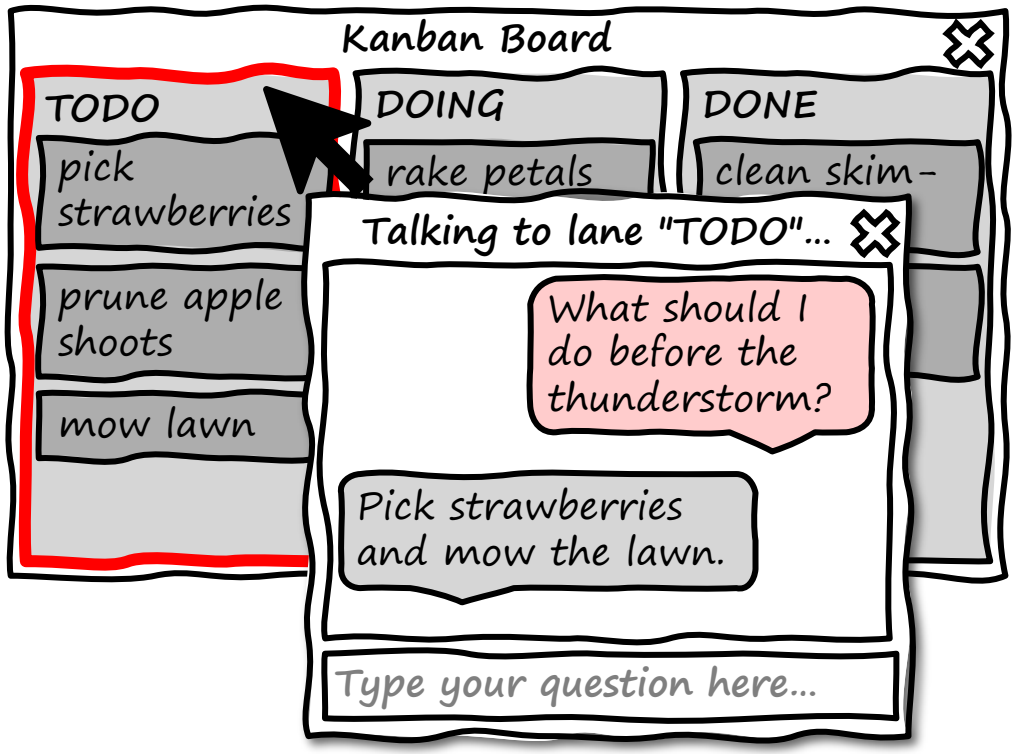
Function	Description
`eval(expression)` *Example:* `eval("self customer")`	Evaluate a Smalltalk expression in the context of the explored object and return the result or error. Can be executed in isolation.
`evalAndReturn(expression)`	Evaluate a Smalltalk expression in the context of the explored object and pass back the result to the sender of the original semantic message. Only available if the agent was invoked through a semantic message.
`browsePackage(packageName)`	Return a hierarchical list of classes within a package.
`browseClass(className)`	Enumerate all methods defined on a class or one of its superclasses or their metaclasses (for static methods), grouped by the defining class and the method category (protocol) within the class organization.
`browseMethod(className, selector)`	Retrieve the source code of a method defined in a class.

`browseSenders(selector[, query])`
Examples:
`browseSender("printOn:")`
`browseSender("printOn:",`
`  "date yyy-mm-dd")`
	Search the system for all methods that send messages with the name of a selector and return a subset.

Demo

Toward a Semantic Toolset

- Idea: Allow users of object-oriented user interfaces to talk to domain objects on their screen



Toward a Semantic Toolset

- Idea: Allow users of object-oriented user interfaces to talk to domain objects on their screen
- Many exploratory programming tools employ object-oriented interfaces:
  - Structural navigation tools (such as Smalltalk code browsers)
  - Projectional editors (based on AST)
  - Symbolic debuggers (based on process/call stack)
  - Profilers (based on trace)
  - ...

Discussion

- Feasibility of the exploratory programming agent
- Programming experience of semantic object interfaces

Discussion: Feasibility

- **Limitations of LLMs**

Errors
Hallucinations, incorrect reasoning, invalid code

Failures
Insufficient answers, endless trial & error, refused tasks

Train specific abilities?
- Proficiency with Squeak/Smalltalk language + frameworks
- Exploratory practice

- **Performance**

	Response times	Monetary cost	
Simple tasks	2 s – 4 s	$0.10 – $0.50	$1 – $60 per hour [KUB2018]
Complex tasks	5 s – 15 s	$0.5 – $5	

Fine-tuned or small language models? [MAG2023]
Optimize prompts?

Discussion: Programming Experience

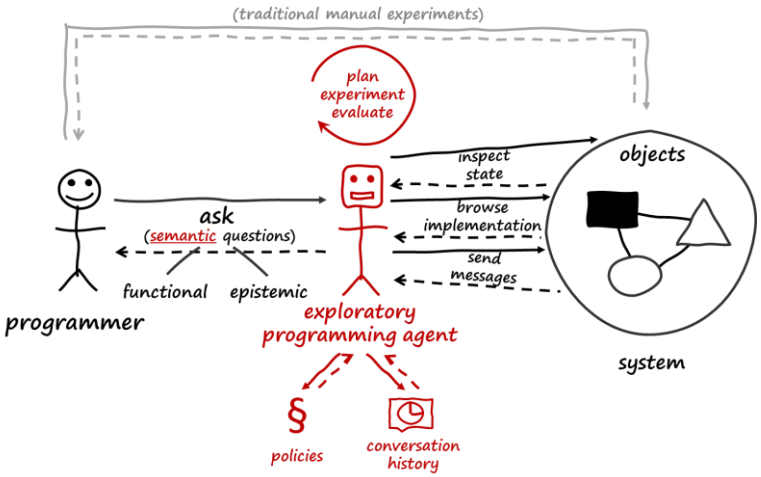
- Higher abstraction level
  - \+ Reduced interruptions and cognitive overhead
  - \+ Improved semantic immediacy and flow [CSI2008]
  - – Leaky abstractions [SPO2004]
  - – Missed serendipitous discoveries
- Natural-language interface
  - \+ Reduced gulf of execution and evaluation
  - \+ Implicit context
- Current LLMs
  - – Limited trust
  - – Temporal distances for complex questions
  - – Fear of expenses
  - – Energy & water consumption [LI2023]

Future Work

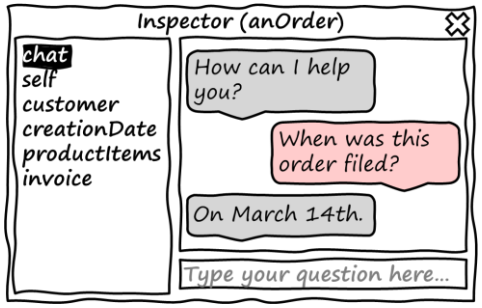
- How can we improve the capability and performance of the exploratory programming agent?
  - … by fine-tuning a smaller language model?
  - … by optimizing prompts and function interfaces?
- How can we improve the collaboration of programmers and exploratory agents? [THI2024]
  - … by collecting further implicit context for agents?
  - … by improving the explanation of semantic answers?
  - … by separating responsibilities between programmers and agents more clearly?

Conclusion

Semantic object interfaces

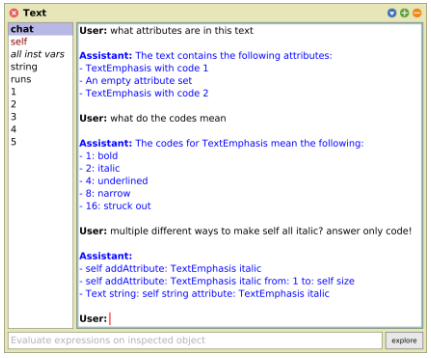


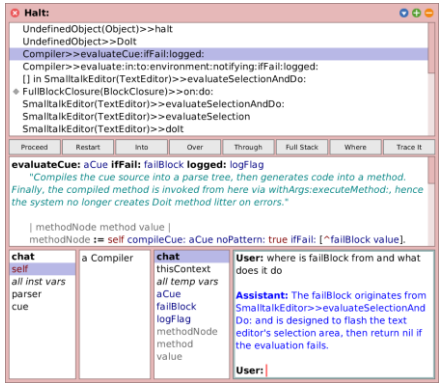
Integrations into programming systems




```
aProduct orderItems mostOftenBoughtOne.
aProduct numberOfSalesTo: aCustomer.
aProduct countSalesFrom: '2023Q3' to: '2023Q4'.
```

Applications





Findings

- Semantic object interfaces improve semantic experience, reduce cognitive overhead, and avoid distractions
- Programmers delegate control and miss serendipitous discoveries
- Need to optimize and fine-tune LLMs for exploratory programming

Thank you!

Further Information

- Christoph Thiede, Marcel Taeumel, Lukas Böhme, and Robert Hirschfeld. **Talking to Objects in Natural Language: Toward Semantic Tools for Exploratory Programming.** In: *Proceedings of the 2024 ACM SIGPLAN International Symposium on New Ideas, New Paradigms, and Reflections on Programming and Software (Onward! '24)*, October 23–25, 2024, Pasadena, CA, USA. ACM, New York, NY, USA, 17 pages. https://doi.org/10.1145/3689492.3690049
- Poster: https://linqlover.github.io/LinqLover/posters/Onward24%20Talking%20to%20Objects.pdf
- Artifacts:
  - https://github.com/hpi-swa-lab/SemanticSqueak
  - https://github.com/hpi-swa-lab/Squeak-SemanticText

Literature

- [BAR2023] Shraddha Barke, Michael B. James, and Nadia Polikarpova. 2023. Grounded Copilot: How Programmers Interact with Code-Generating Models. *Proceedings of the ACM on Programming Languages 7*, OOPSLA1, Article 78 (4 2023), 27 pages. https://doi.org/10.1145/3586030
- [BEC2020] Tom Beckmann, Stefan Ramson, Patrick Rein, and Robert Hirschfeld. 2020. Visual Design for a Tree-Oriented Projectional Editor. In *Companion Proceedings of the 4th International Conference on the Art, Science, and Engineering of Programming* (Porto, Portugal) *(<Programming> '20 Companion)*. ACM, New York, NY, USA, 113–119. https://doi.org/10.1145/3397537.3397560
- [CSI2008] Mihaly Csikszentmihalyi. 2008. *Flow: The Psychology of Optimal Experience* (1 ed.). Harper Perennial, New York. ISBN: 978-0-06-133920-2
- [KUB2018] Juraj Kubelka, Romain Robbes, and Alexandre Bergel. 2018. The Road to Live Programming: Insights from the Practice. In *Proceedings of the 40th International Conference on Software Engineering* (Gothenburg, Sweden) *(ICSE '18)*. ACM, New York, NY, USA, 1090–1101. https://doi.org/10.1145/3180155.3180200
- [NOR1986] Donald A. Norman. 1986. *Cognitive Engineering.* Lawrence Erlbaum, Hillsdale, NJ, USA, 31–61.
- [REI2019] Patrick Rein, Stefan Ramson, Jens Lincke, Robert Hirschfeld, and Tobias Pape. 2019. Exploratory and Live, Programming and Coding: A Literature Study Comparing Perspectives on Liveness. *The Art, Science, and Engineering of Programming* 3, 1 (07 2019), 33 pages. https://doi.org/10.22152/programming-journal.org/2019/3/1
- [SAN1988] David W. Sandberg. 1988. Smalltalk and Exploratory Programming. *SIGPLAN Not.* 23, 10 (1988), 85–92. https://doi.org/10.1145/51607.51614
- [SPO2004] Joel Spolsky. *Joel on Software: And on Diverse and Occasionally Related Matters That Will Prove of Interest to Software Developers, Designers, and Managers, and to Those Who, Whether by Good Fortune or Ill Luck, Work with Them in Some Capacity.* Berkeley, CA, USA: Apress, 2004. ISBN: 978-1-59059-389-9
- [TAE2022] Marcel Taeumel, Jens Lincke, Patrick Rein, and Robert Hirschfeld. 2022. A Pattern Language of an Exploratory Programming Workspace. In *Design Thinking Research: Achieving Real Innovation,* Christoph Meinel and Larry Leifer (Eds.). Springer, Cham, 111–145. https://doi.org/10.1007/978-3-031-09297-8_7
- [THI2024] Christoph Thiede. 2024. *The Semantic Workspace: Augmenting Exploratory Programming with Integrated Generative AI Tools.* Master Thesis (to be defended). Hasso Plattner Institute, University of Potsdam. https://github.com/LinqLover/semexp-thesis/releases/download/submission/semexp-thesis-oneside.pdf
- [UNG1997] David Ungar, Henry Lieberman, and Christopher Fry. 1997. Debugging and the Experience of Immediacy. *Communications of the ACM* 40, 4 (apr 1997), 38–43. https://doi.org/10.1145/248448.248457

Literature (AI)

- [CHE2021] Mark Chen et al . 2021. *Evaluating Large Language Models Trained on Code.* arXiv:2107.03374 [cs.LG]
- [LEW2020] Patrick Lewis, Ethan Perez, Aleksandra Piktus, Fabio Petroni, Vladimir Karpukhin, Naman Goyal, Heinrich Küttler, Mike Lewis, Wen-tau Yih,Tim Rocktäschel, Sebastian Riedel, and Douwe Kiela. 2020. Retrieval-Augmented Generation for Knowledge-Intensive NLP Tasks. In *Advances in Neural Information Processing Systems* (Vancouver, Canada) *(NIPS '20, Vol. 33)*, Hugo Larochelle et al. (Eds.). Curran, RedHook, NY, USA, Article 793, 16 pages. ISBN: 978-1-7138-2954-6. arXiv:2005.11401 [cs.CL]
- [LI2023] Pengfei Li, Jianyi Yang, Mohammad A. Islam, and Shaolei Ren. 2023. Making AI Less "Thirsty": Uncovering and Addressing the Secret Water Footprint of AI Models. arXiv:2304.03271 [cs.LG]
- [MAG2023] Lucie Charlotte Magister et al. 2023. Teaching Small Language Models to Reason. In *Proceedings of the 61st Annual Meeting of the Association for Computational Linguistics*, Anna Rogers, Jordan Boyd-Graber, and Naoaki Okazaki (Eds.), Vol. 2: Short Papers. Association for Computational Linguistics, Toronto, Canada, 1773–1781. https://doi.org/10.18653/v1/2023.acl-short.1511
- [RAD2018] Alec Radford, Karthik Narasimhan, Tim Salimans, Ilya Sutskever, et al. 2018. *Improving Language Understanding by Generative Pre-Training.* https://openai.com/research/language-unsupervised
- [WAY2023] Wayne Xin Zhao et al . 2023. *A Survey of Large Language Models.* 124 pages. arXiv:2303.18223 [cs.CL]
- [WHI2023] Jules White et al. 2023. *A Prompt Pattern Catalog to Enhance PromptEngineering with ChatGPT.* 19 pages. arXiv:2302.11382 [cs.SE]