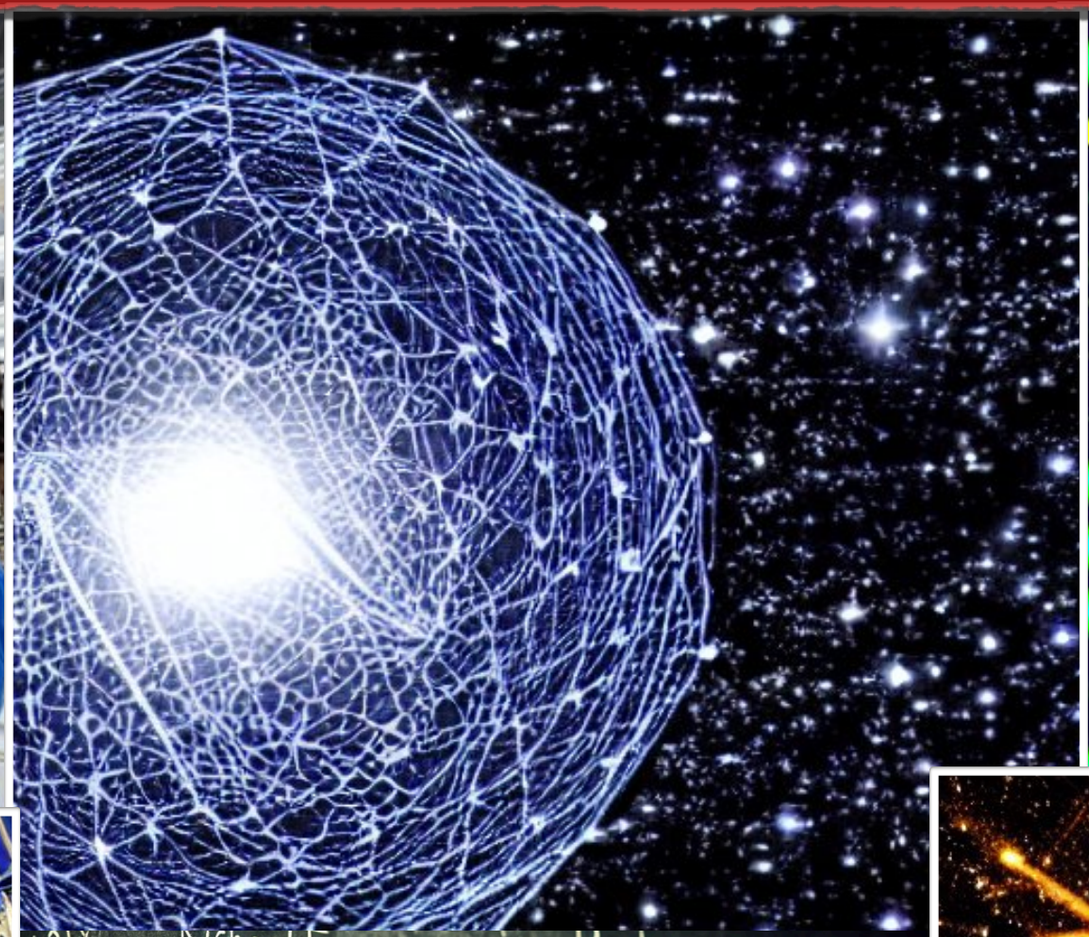
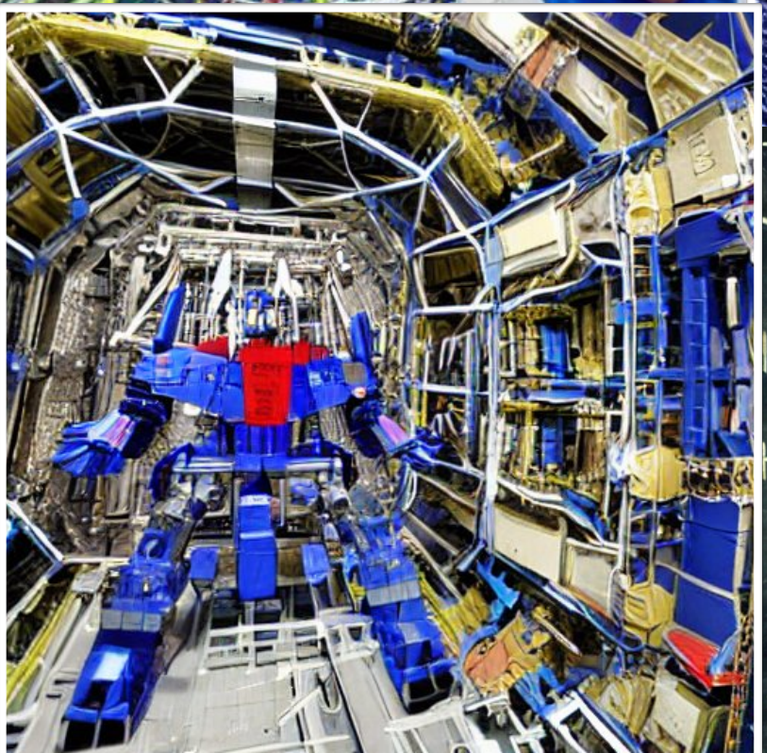
COMAP-XI AT CERN

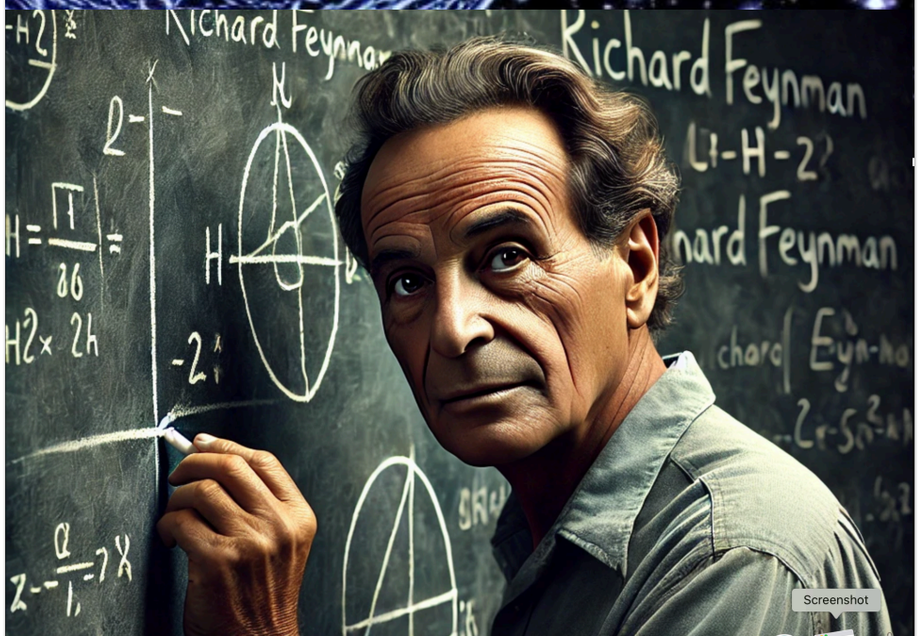
3 Feb 2025

Future prospective of involving AI in research

Hrayr Matevosyan







AI APPLICATIONS IN PHYSICS

Applications of LLMs and optimisation:

- *Language Models:*
  - *Literature search in scientific articles:*
    Questions Answering / Summarisation.
  - *Analysis code: Code generation / documentation.*
- *Optimisation:*
  - *Experiment Shift Personnel Scheduling.*
  - *Detector Design Optimisation.*

NATURAL LANGUAGE PROCESSING (NLP)

Creating programs that "understand" and process natural language such as text and speech.

- *Tasks:*
  - Named Entity Recognition
  - Question Answering
  - Machine Translation
  - Text Generation
  - Sentiment Analysis
  - Summarisation

- *Extremely Challenging:*

  Often need additional context: "The Silver Arrows were trampled by the Prancing Horse this season".

CONTEXT MATTERS

- *Extremely Challenging: often need "world knowledge"*

"The Prancing Horse trampled the Silver Arrows on the track".

LARGE LANGUAGE MODELS (LLM)

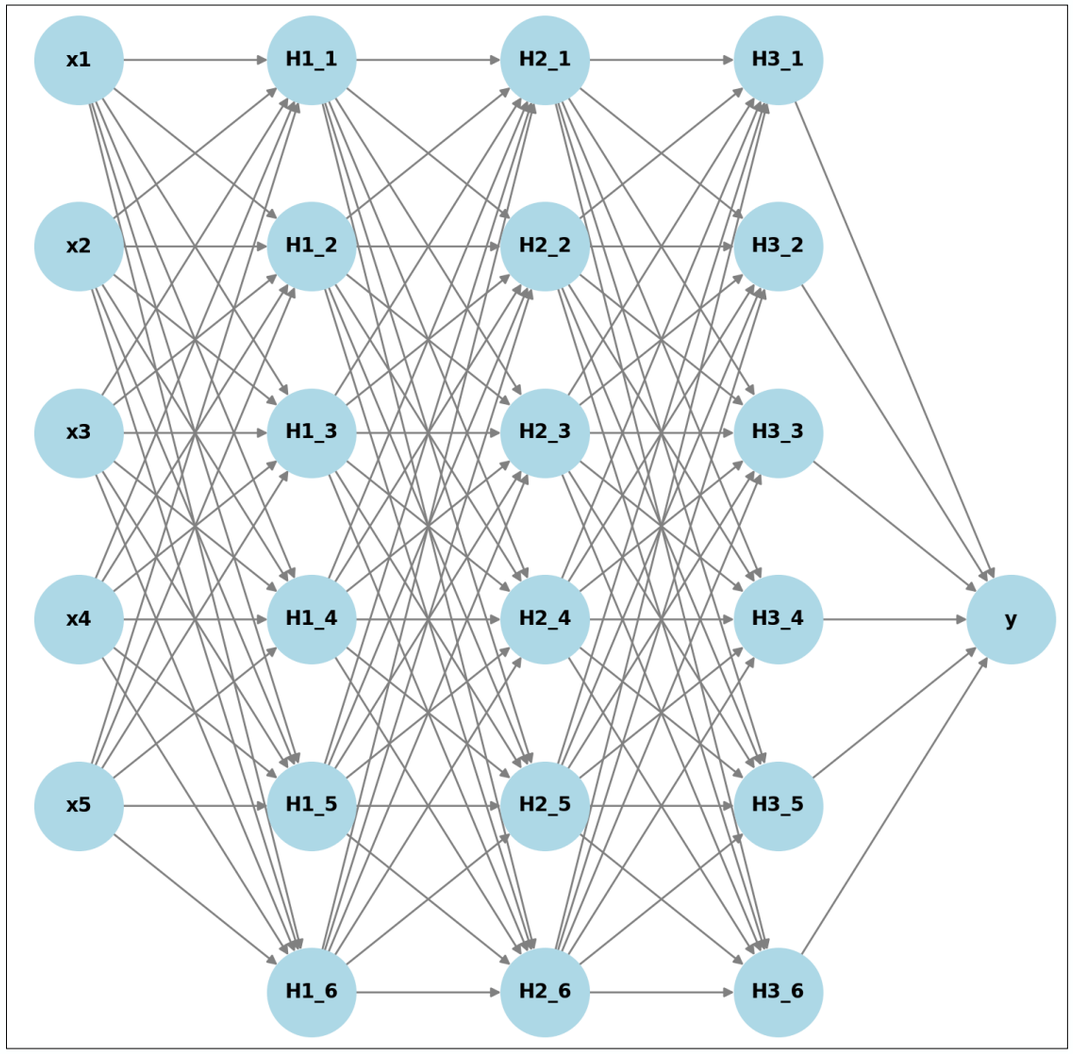
Breakthroughs: *Transformers (2017) and Transfer Learning (2018)*
Generative AI / "Reasoning Models" - Inference time compute

- ***Fundamentally: "next token prediction" models***
  - **Pre-training (Unsupervised Learning) - next token prediction**
  - **Fine-Tuning (Supervised/Task-Specific Training) - follow instructions**
  - **Alignment and Reinforcement Learning with Human Feedback (RLHF)**
- ***Very large up to ~ 10^{12}*** *parameters !*
- ***Encode "world knowledge"*** *- knows what "Prancing Horse" refers to.*
- ***Hallucinations*** *- will always produce an answer, can give an answer that "mimics" the correct one.*

LARGE LANGUAGE MODELS (LLM)

x y

The measurements of the azimuthal asymmetries in two-hadron production in semi-inclusive deep inelastic scattering (SIDIS) process have been recently analyzed to extract the nucleon transversity



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ADVANCED SEARCH
QUESTION ANSWERING (QA)

Answers to scientific question:

LLMs (GPT, Claude)	*+Search (Perplexity)*	*Generative QA (RAG)*	*Extractive QA*
Snapshot of internet.	*Search "fresh" data.*	*Use relevant texts.*	*Use relevant texts.*
Generate answers.	*Generate answers.*	*Generate answers.*	*Highlight the answers.*
Hallucinations	*Hallucinations*	*Hallucinations*	*Cannot combine parts*
Slow	*Slow*	*Slow*	*Fast*

Generative Models can represents the "average opinion"
NO critical reasoning!

Extractive + Generative QA

CODE GENERATION

- *The latest generation of "reasoning" models can generate high quality code in Python / Java / C++, etc.*

- *Large "context windows"* ~10^5 *: include the relevant parts of existing code / documentation.*

- *The generated code can be auto "tested" using "agents":*
  Check for code execution / results consistent with the physics.

- *Document existing convoluted code.*

OPTIMISING PERSONNEL SCHEDULING

- **The Need:**
  - *Cover all the stations w/ specialists*
  - *Peoples availability / expertise*
  - *Cove the breaks (meals/rest)*
  - *Preference / Fairness*

- **Re-Scheduling:**
  - *Disruptions in experiments*
  - *Absences / change of availability*
  - *People leaving / joining the experiment*

- **Outcomes:**
  - *Reduced Planning time / effort*
  - *Fairness*
  - *Happy(er) scientists*

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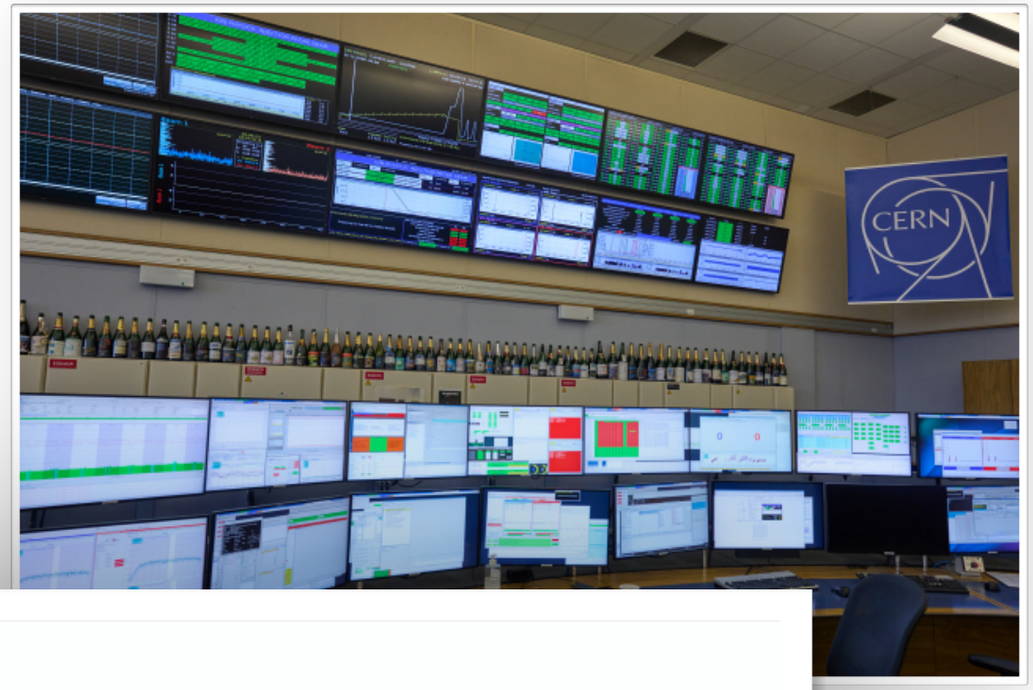


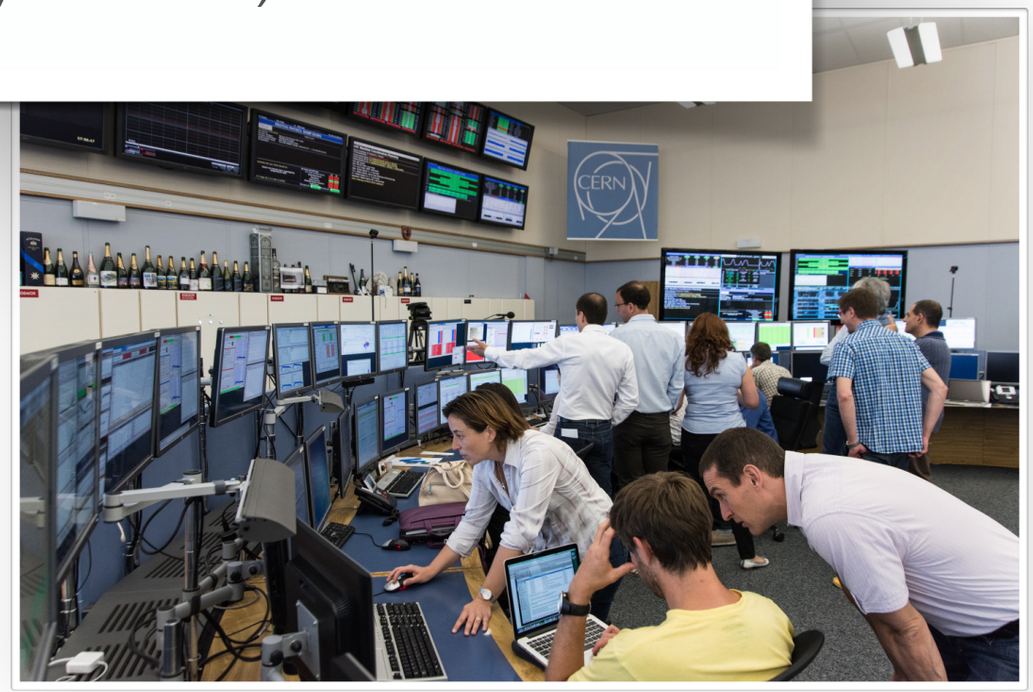
- **Re-Sc**
  - *Disrup*
  - *Absenc*
  - *People*

NP*-HARD Problem:

Number of shift combinations grows exponentially !

**NP (nondeterministic polynomial time)*

- **Outcomes:**
  - *Reduced Planning time / effort*
  - *Fairness*
  - *Happy(er) scientists*

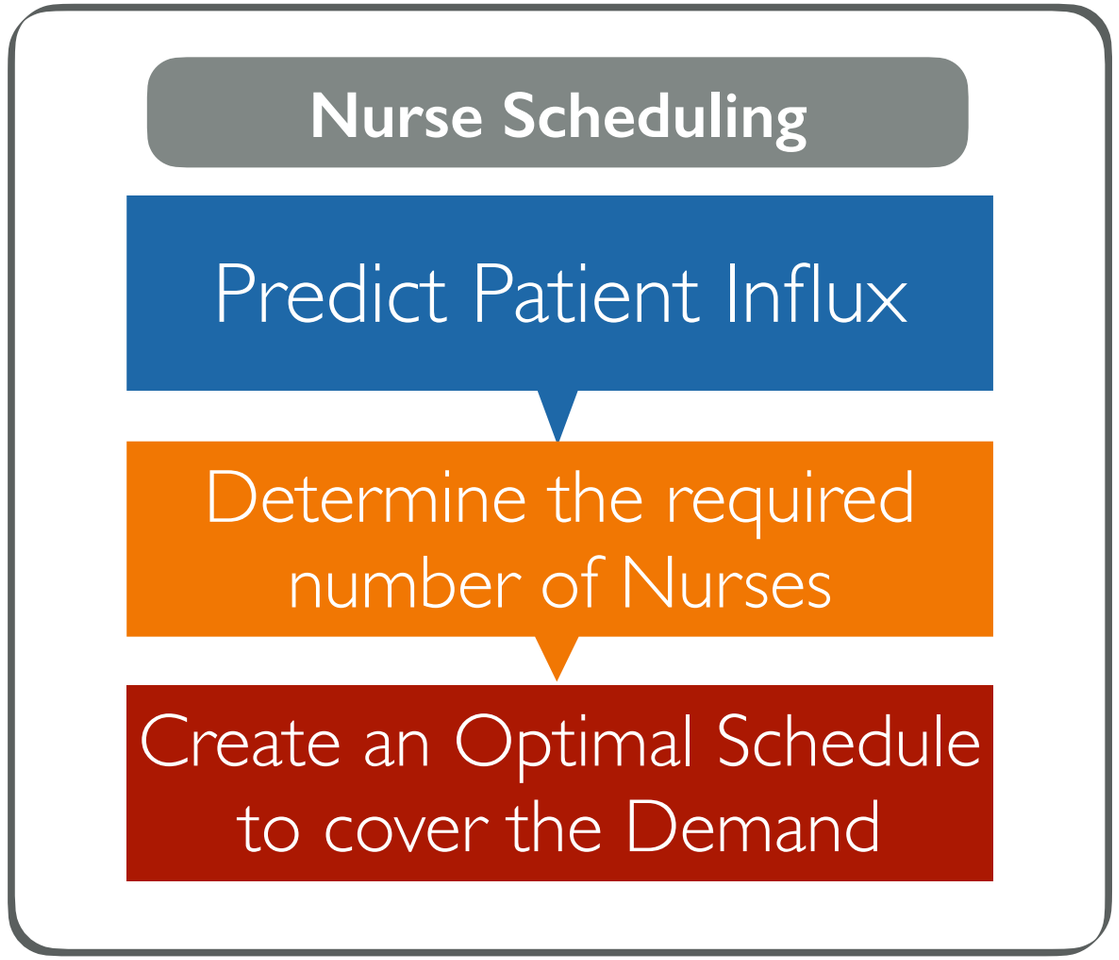


“NURSE SCHEDULING PROBLEM”

- **Well Researched in Operations Research**
  - *Nurse Scheduling*
  - *Pilots / drivers*
  - *Restaurant staff*
  - *Emergency services workers*

- **Re-Scheduling:**
  - *Dynamic Optimisation*
  - *Continuous Planning*

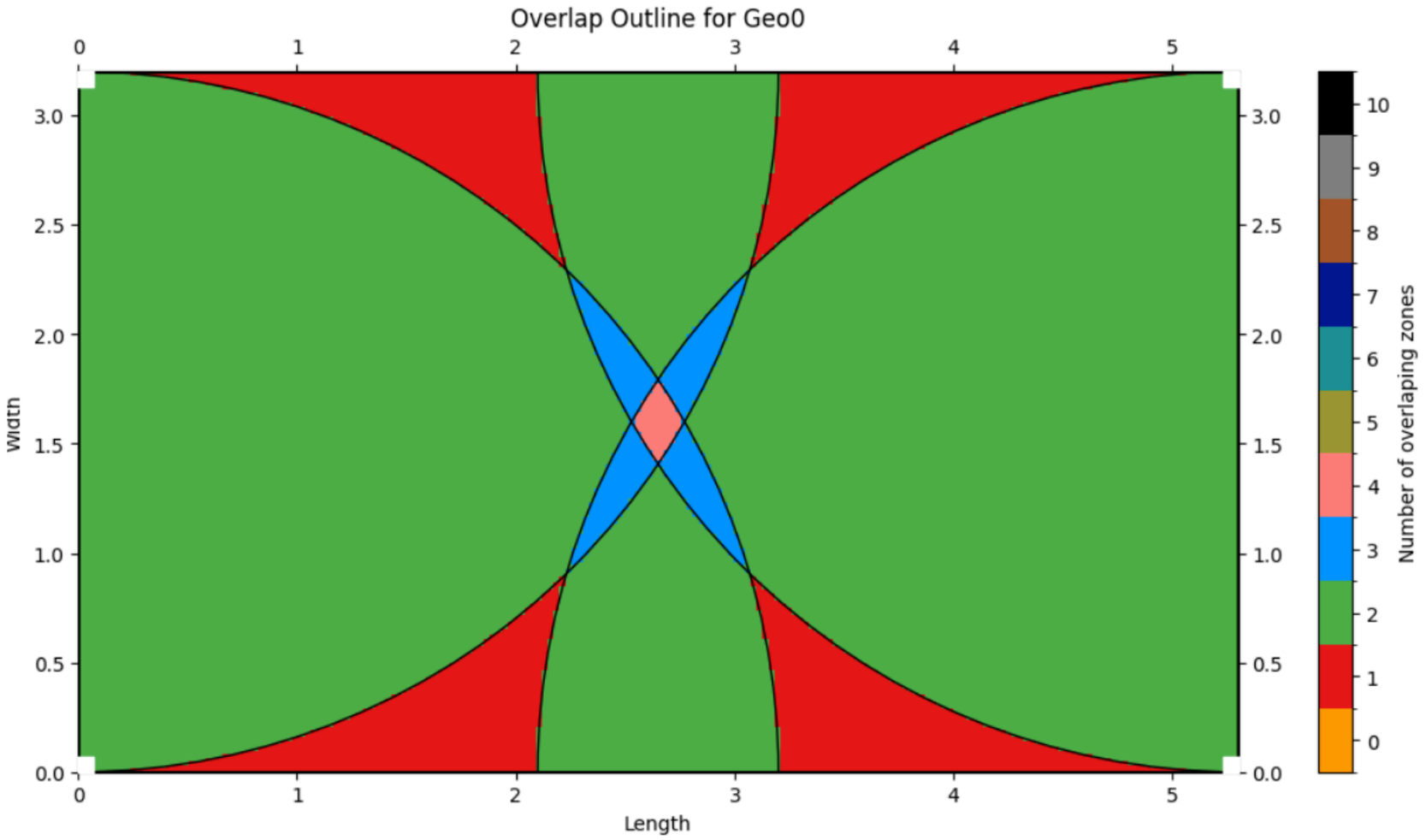
- **Approaches:**
  - *Integer Programming*
  - *Constraint Programming*
  - *Heuristics*



Nurse (Specialty)	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Alice 👶	🟢🟠	❌	🟢🟠	❌	🟢🟠	❌	❌
Mark 🏥	🟢🔵	❌	❌	🟢🔵	❌	🟢🔵	❌
Emily 💉	❌	🔵⚫	❌	🔵⚫	❌	🔵⚫	❌
Robert ❤️	❌	🔵	❌	🔵	❌	🔵	❌
Sophia 🦷	⚫	❌	⚫	❌	⚫	❌	⚫

DETECTOR DESIGN

- **The Need:**
  - *Find the best geometry / material combinations*
  - *Maximise the detector sensitivity / coverage.*
  - *Constrained by physical properties / geometry / cost.*
- **A toy example: find optimal coverage by circle segments:**



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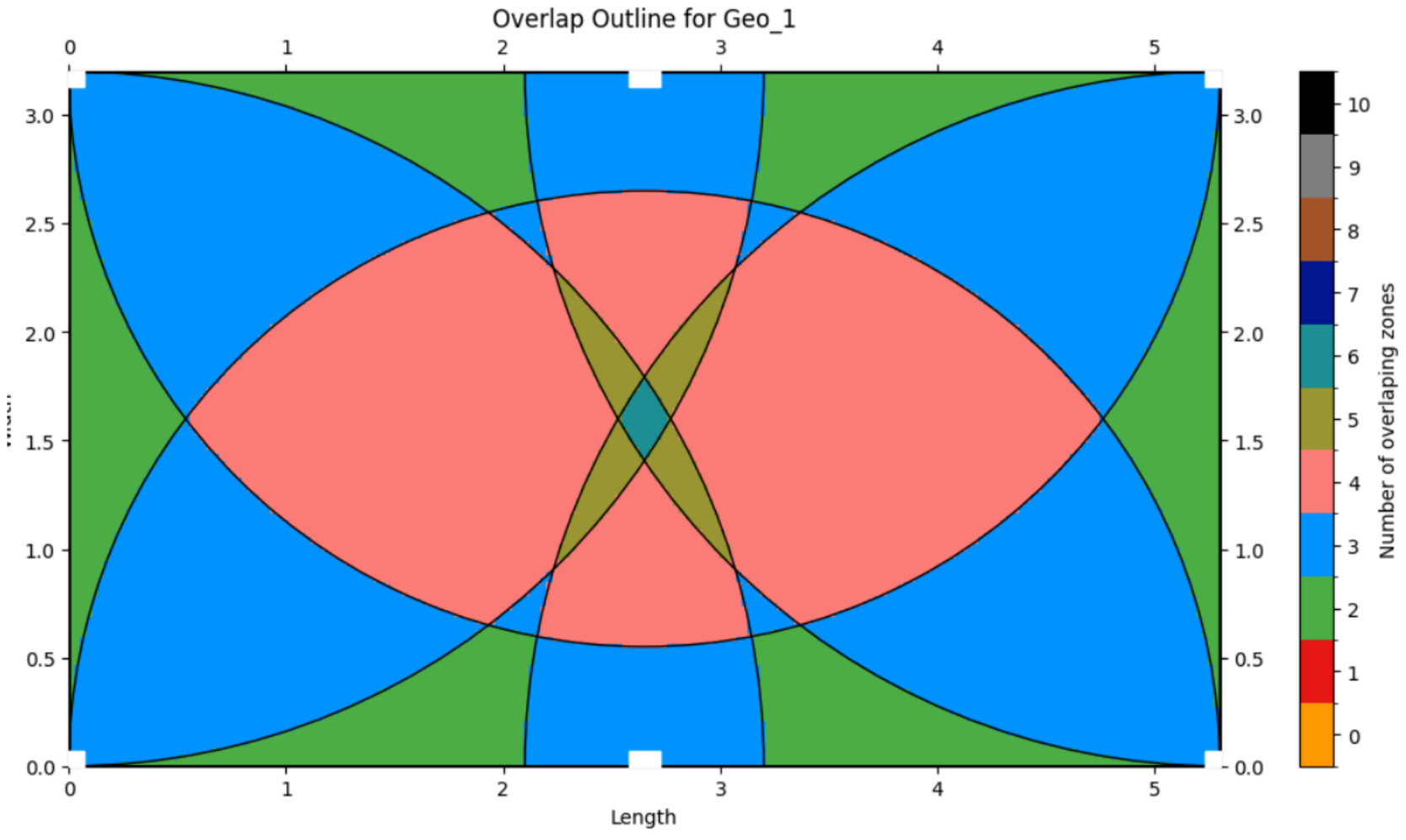

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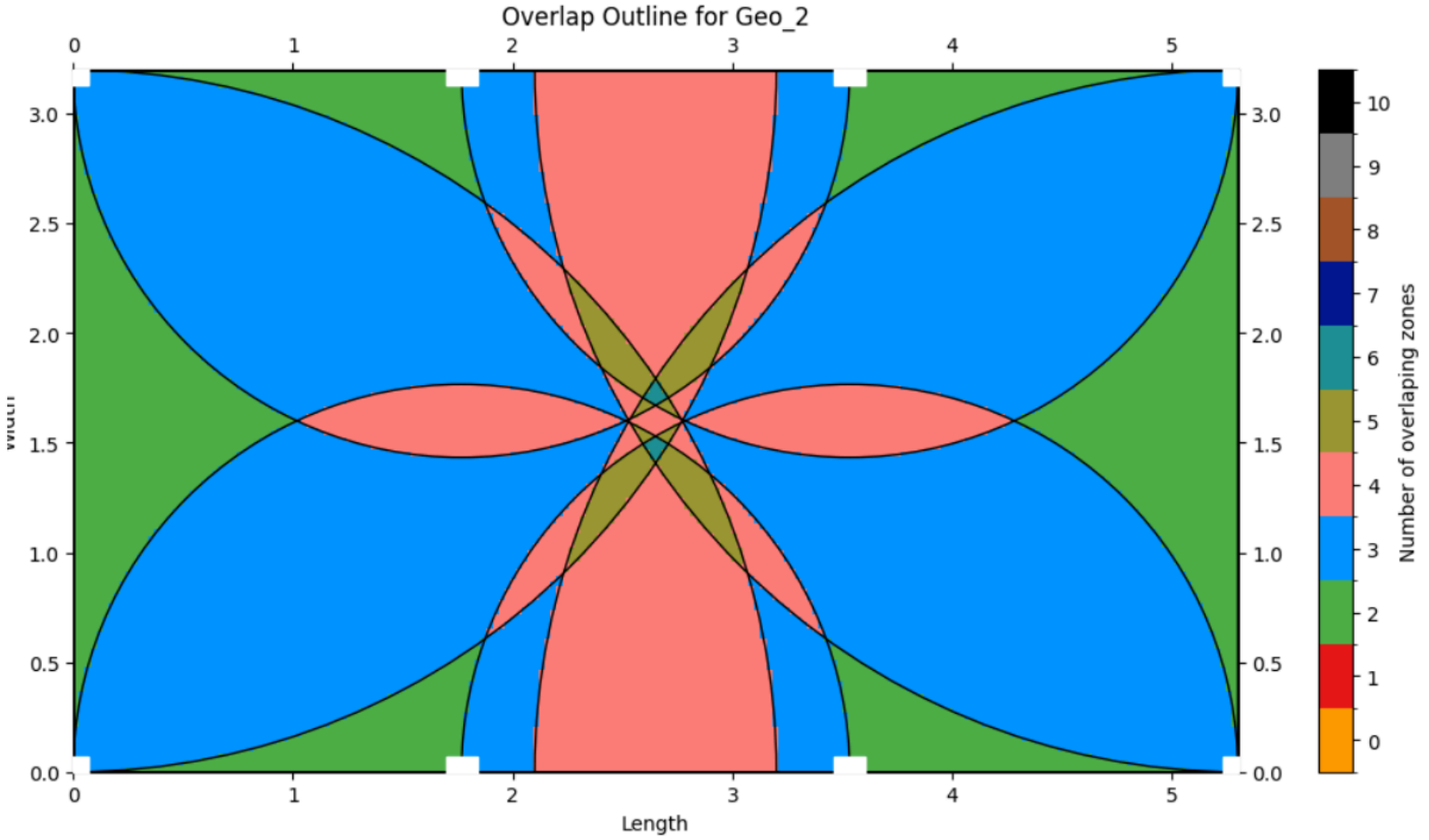

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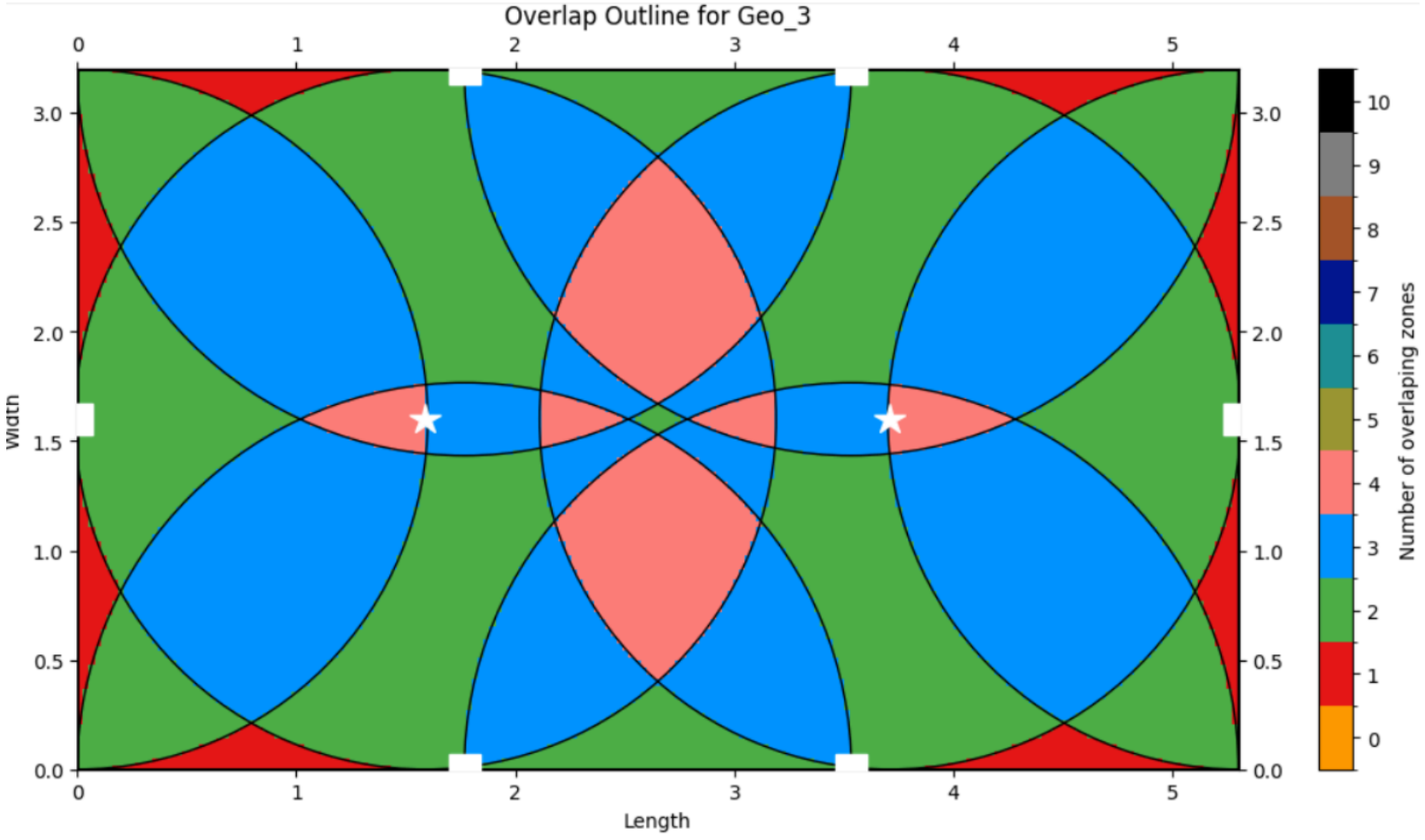

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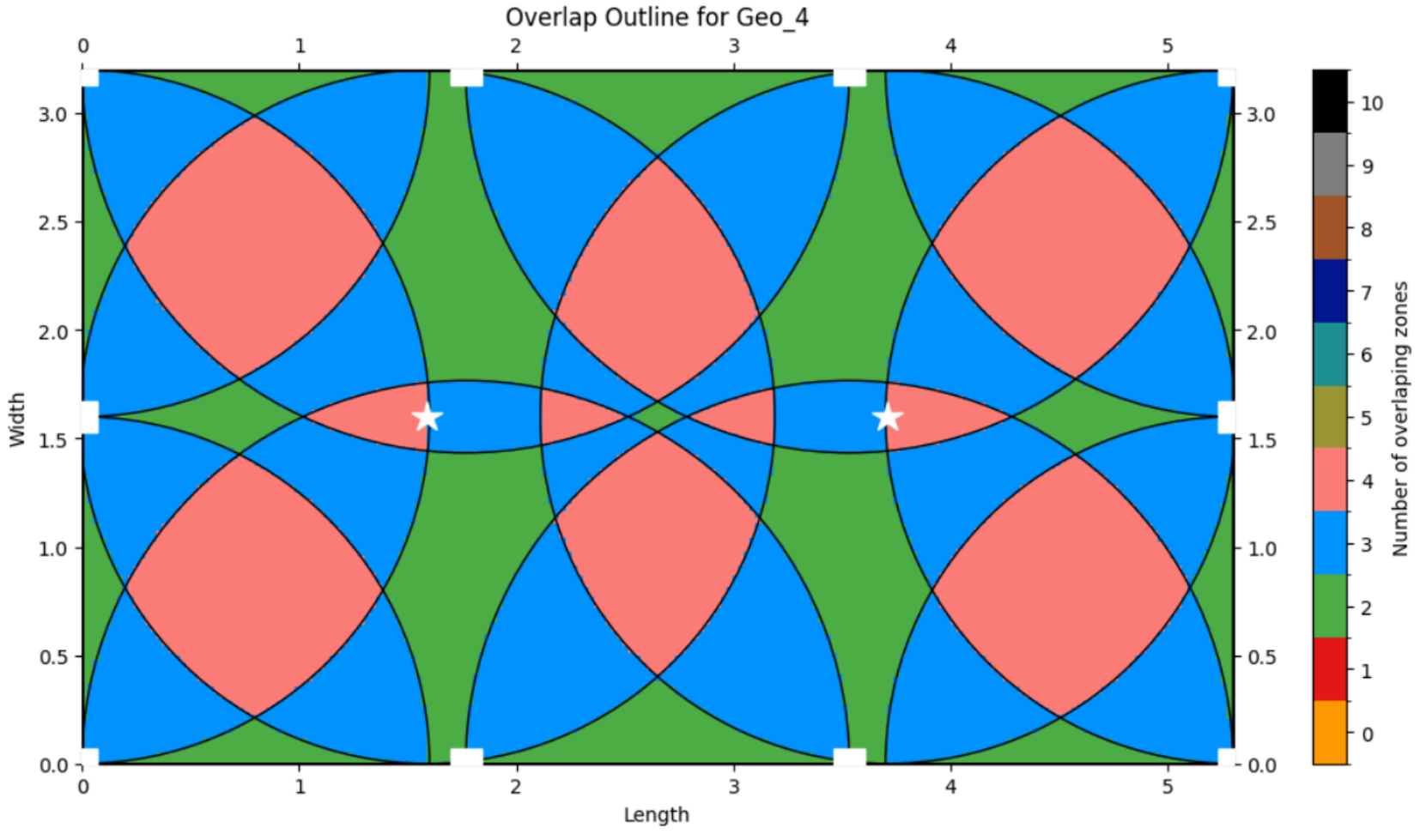

Thank you!