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A software framework for interoperable, plug-and-play, distributed robotic systems-of-systems

Robert Skilton

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Experience from JET – The worlds most powerful nuclear fusion experiment

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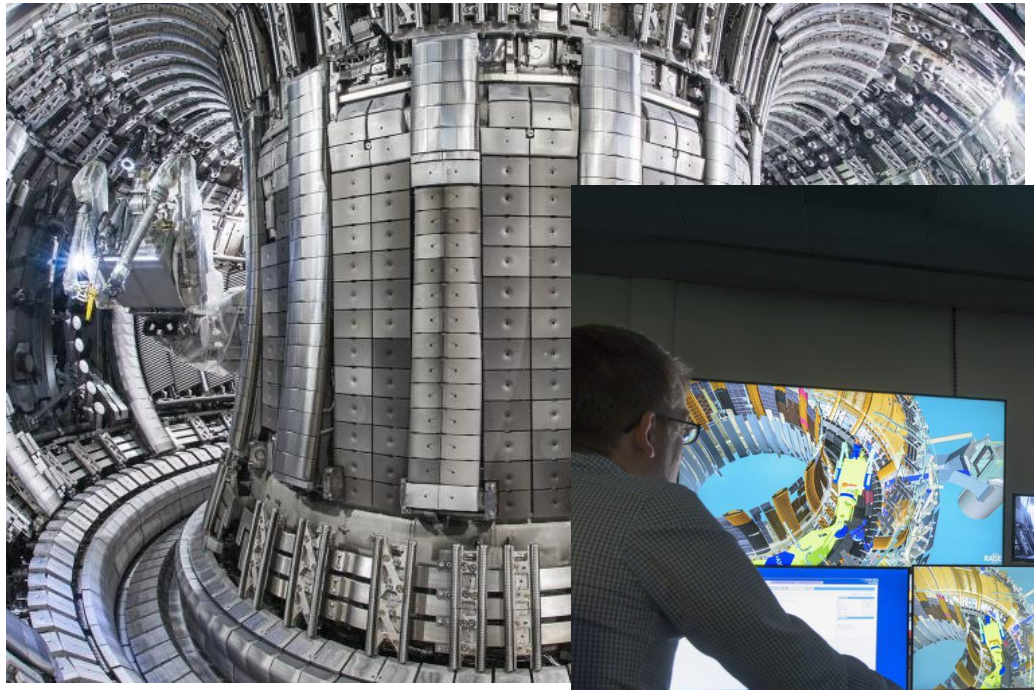
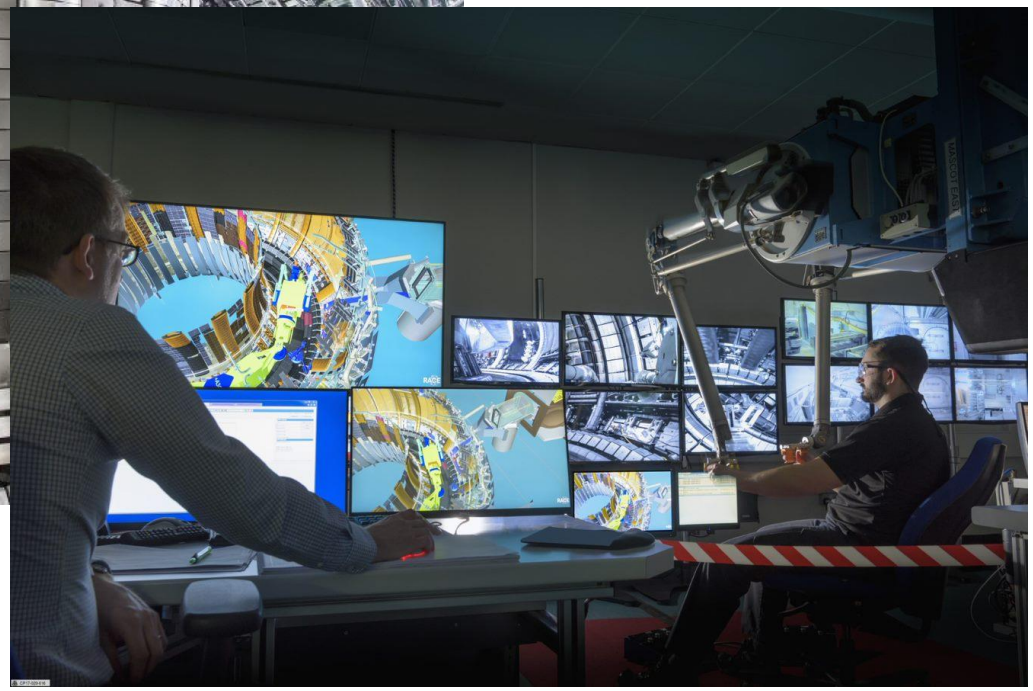
- >30,000 hours of operational experience
- 8 maintenance programmes
- >20 Years of robotic maintenance
- >2000 tools used
- >8500 components handled

Replacement of the entire “first wall”, using over 350 separate remote handling tools and replacing over 7,000 components over 18 months.





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Challenges for large-scale robotic maintenance and decommissioning

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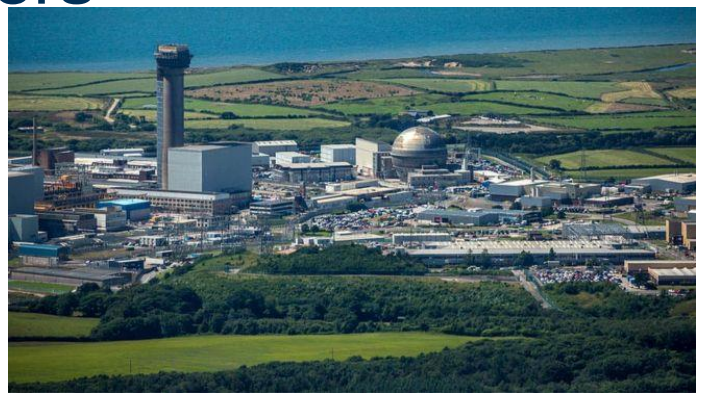
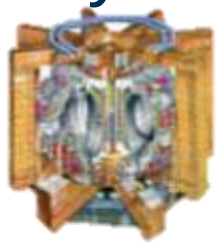
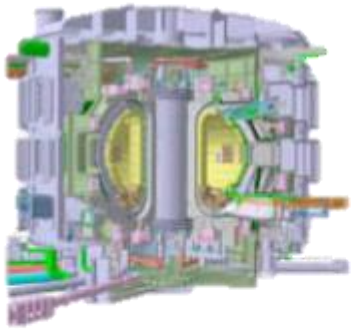
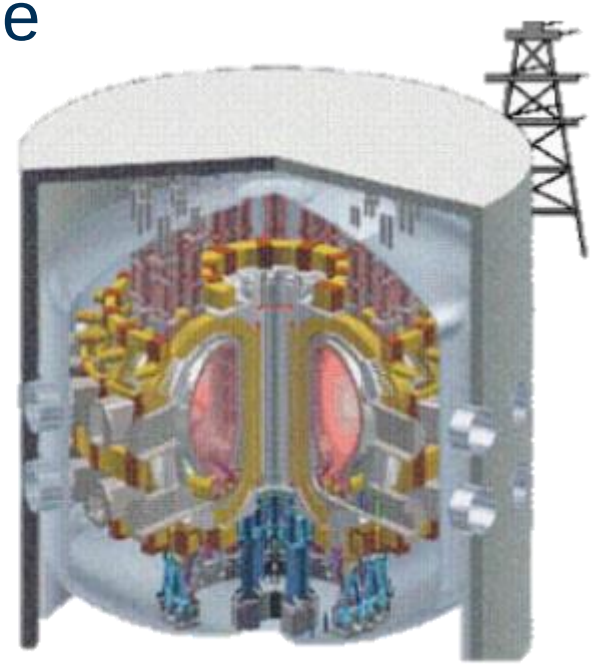
- Integrating (100s of) systems from multiple suppliers
  - Multiple bespoke interfaces
  - Training requirements
- Operational lifetime may be several decades
  - Requirements evolve over time
  - Obsolescence management
- Scalability
- Reliability









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Uses of software in these robotic facilities

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Hardware interface - hardware integration and translation

Control – control methods, generic control laws, motion planning, AI

Sensor processing – signal processing, sensor fusion, feature extraction

HMI & GUI – integrated user interfaces to provide operator control and interaction

Planning & scheduling tools - which can be used to add process and procedure to control tasks.

Virtual & augmented reality - to display information in the form of intuitive 3D visualisations / digital twin.

Condition monitoring - to track patterns and changing conditions in the equipment in order to identify developing faults.

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Design requirements

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Modularity – Control should be implemented in discrete blocks, so that sections can be removed, swapped out, and used in conjunction with other discrete blocks.

Standardisation – Data should use pre-defined, but extendable, data structures. This allows for customisation while keeping as much compatibility as possible.

Extensibility – Control should be implemented in such a way as to allow it to be extended by later applications. For example, a 4-wheeled robot could be extended to control a 6-wheeled robot.

Reusability – Control should be implemented in a generic fashion. For example, a 4-wheeled robot is controlled as a 4-wheeled robot, rather than brand specific model.

Common, user interfaces – A single, universal, consistent interface for users and developers.

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Object-Oriented Design?

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- Encapsulation
- Abstraction
- Inheritance & Composition
- Polymorphism

Not about the software, but about the system connected by the software.

OO alone does not create interoperability or plug-and-play capability.

Introspection and knowledge of a type hierarchy allows us to go further.

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What is CorteX?

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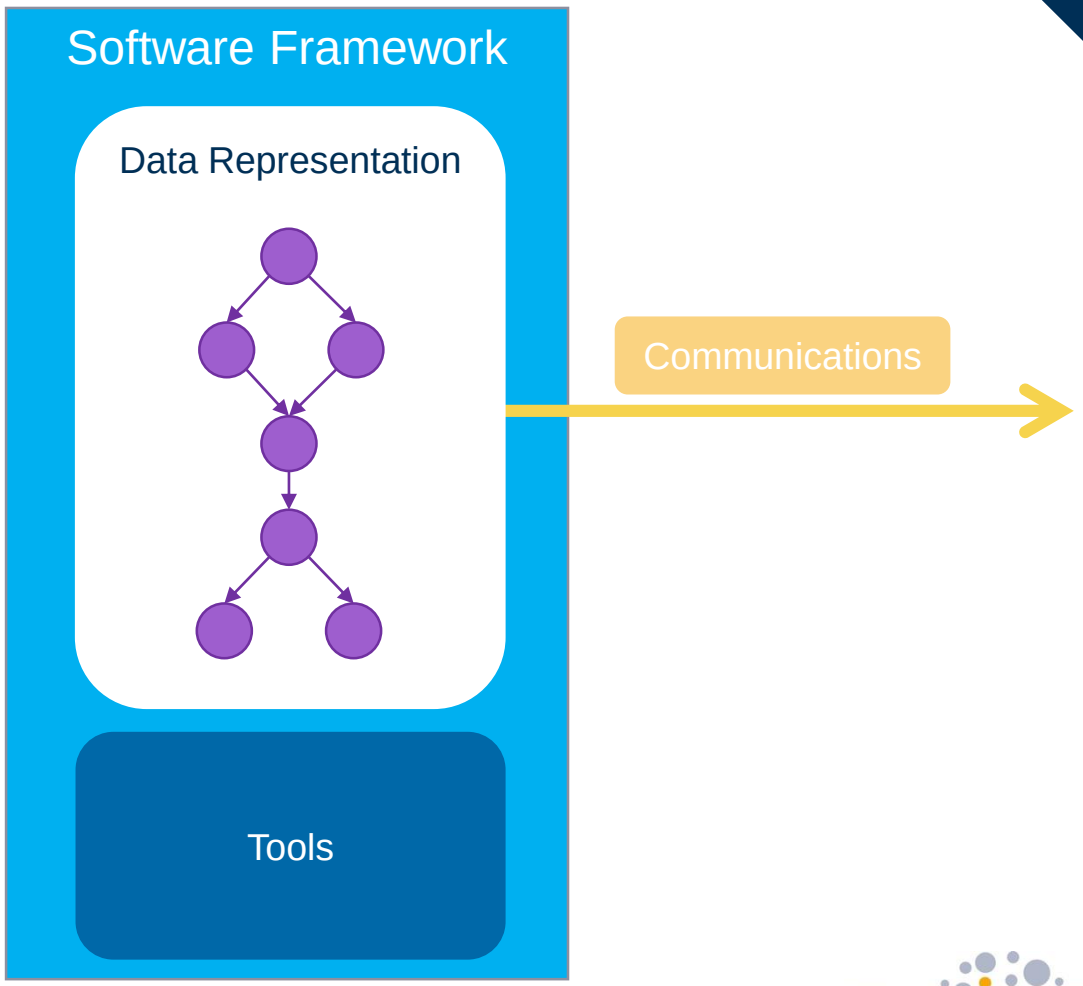
CorteX attempts to solve the main problems associated with interoperable, plug-and-play, distributed robot systems-of-systems, at least from a data/communications perspective.

CorteX could be thought of as:

1. A standardised graphical data representation for robotic systems
2. A method for communicating this representation
3. A software framework that implements the above
4. Additional software tools to add functionality



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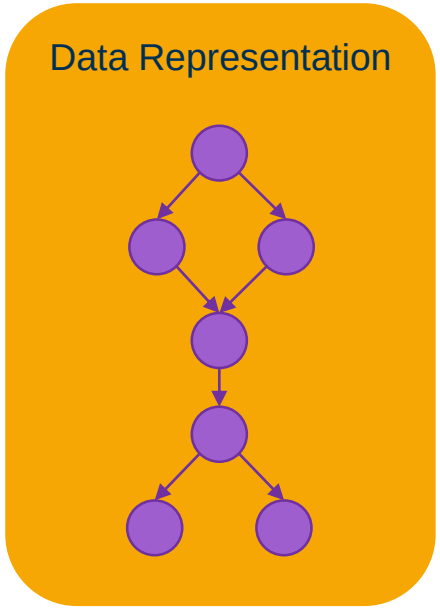
Self-description to allow a single standardised interface

- CorteX uses a self-describing, standardised data representation.
  - Every node (Simplex) in the graph uses the same format.
- This data representation can be used as part of a communications protocol to allow distributed components of a single control system to exchange data without prior knowledge of each other.
- This means a CorteX control system can grow to incorporate new hardware and control features without modifying other distributed components.



Data Representation

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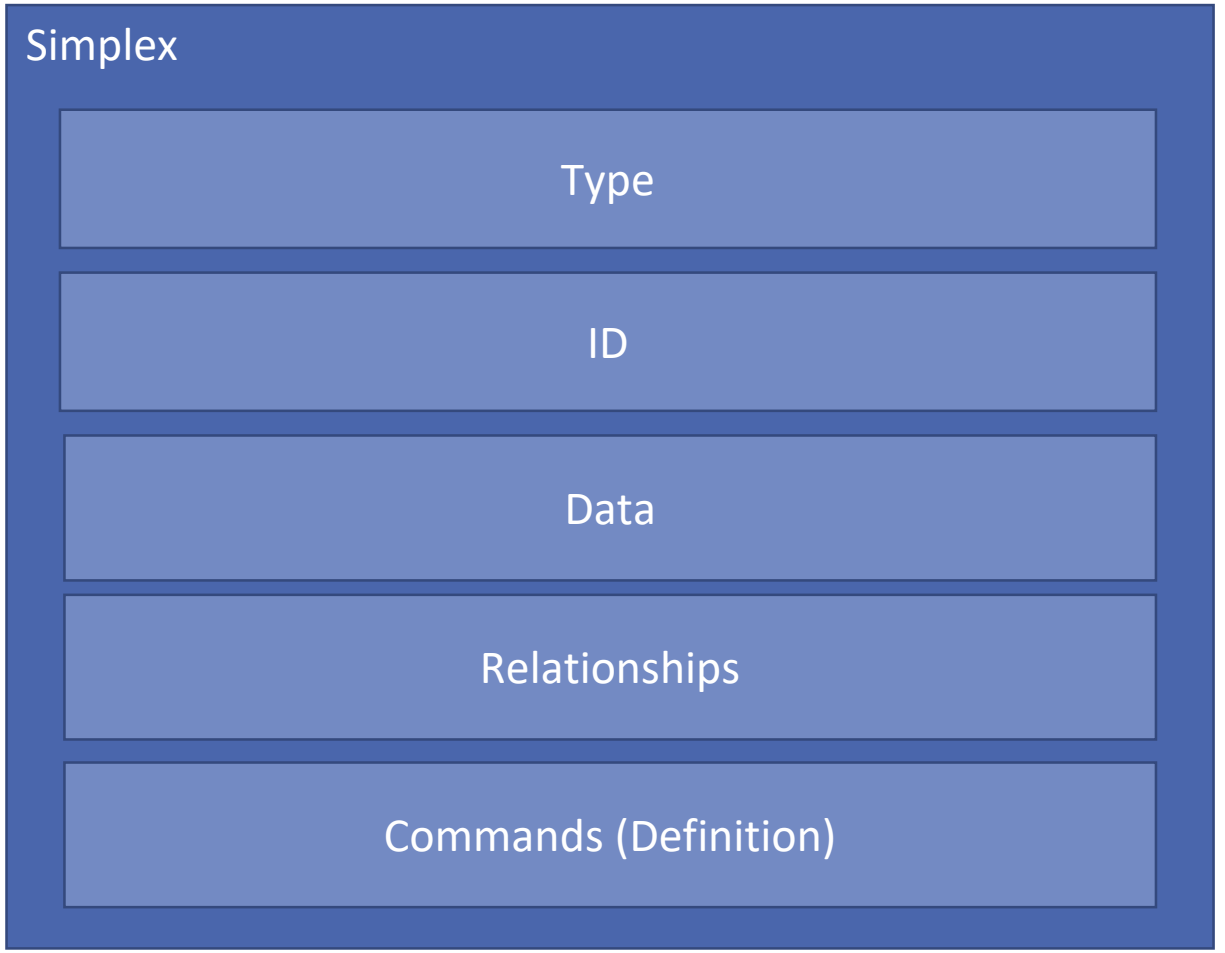
Simplex (graph nodes) Data

- Type (from type hierarchy)
- ID
- Data (name, value pairs)
- Relationships (graph edges)
- Commands (definition of command and parameters)



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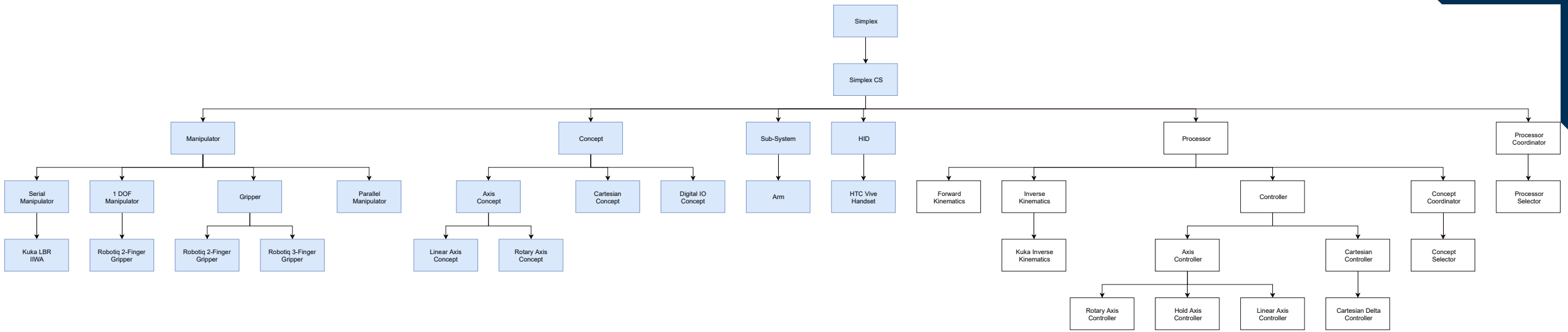
Type Hierarchy



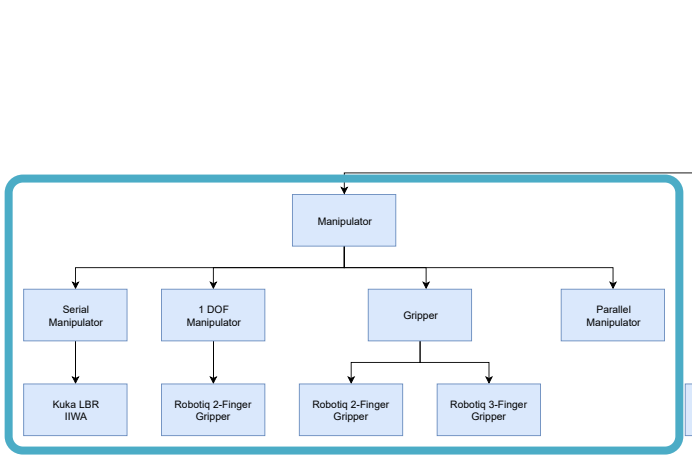
Types

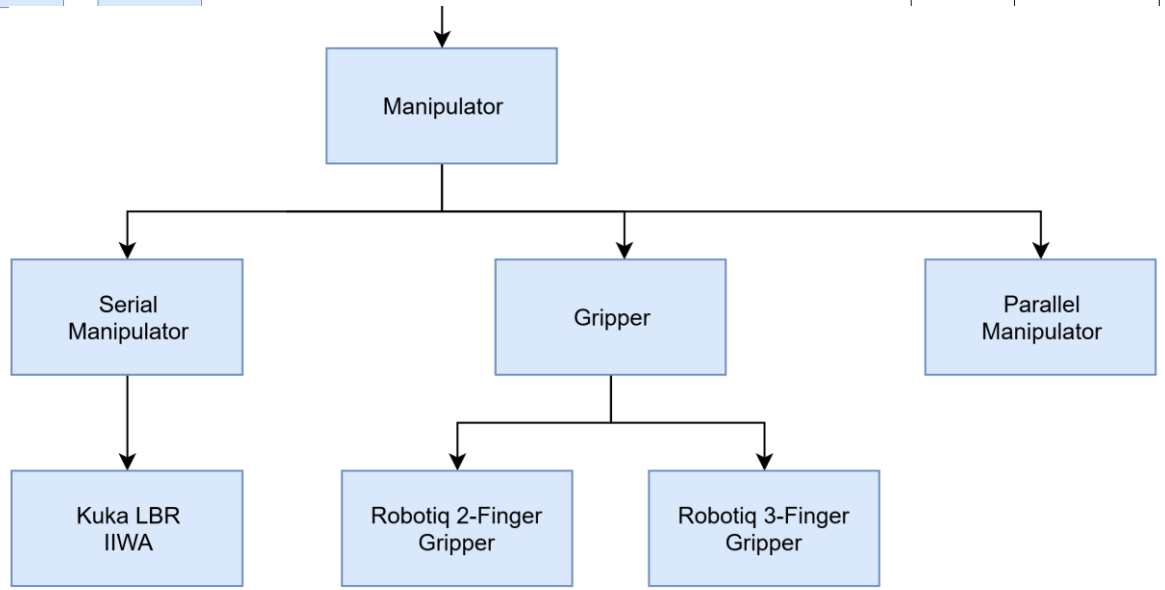
Data Rules

Relationship Rules

Command Rules

Type Hierarchy – Manipulator Example





Structural & Morphological Rules

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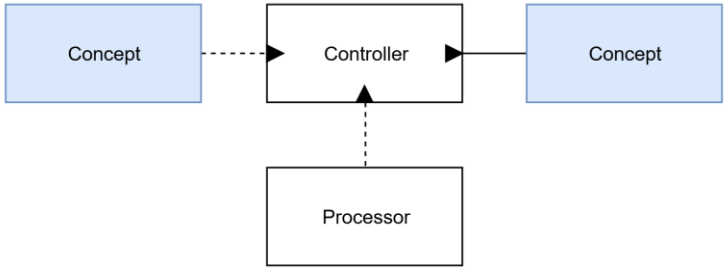
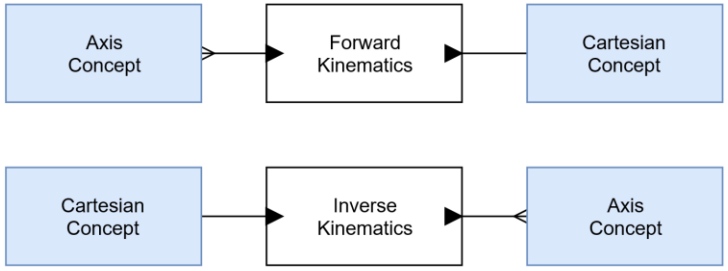
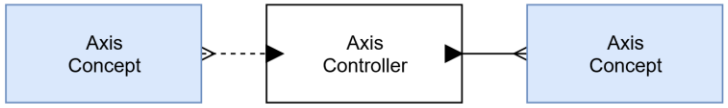
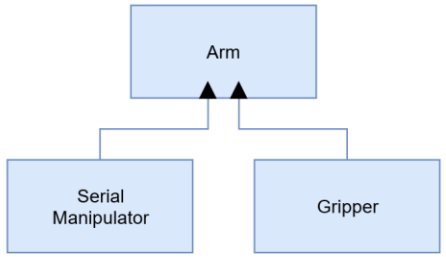
Behavioral Elements

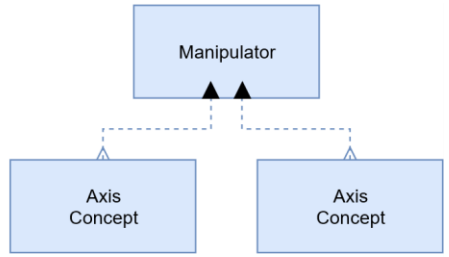


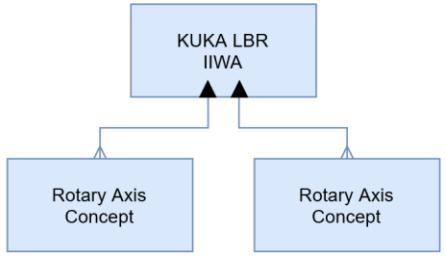


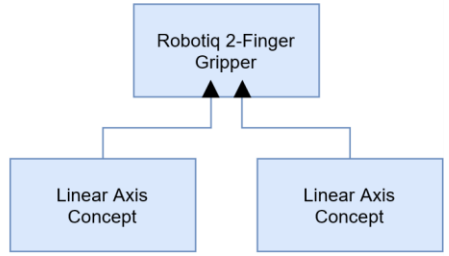


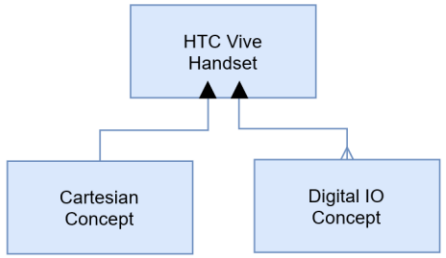
Structural Elements











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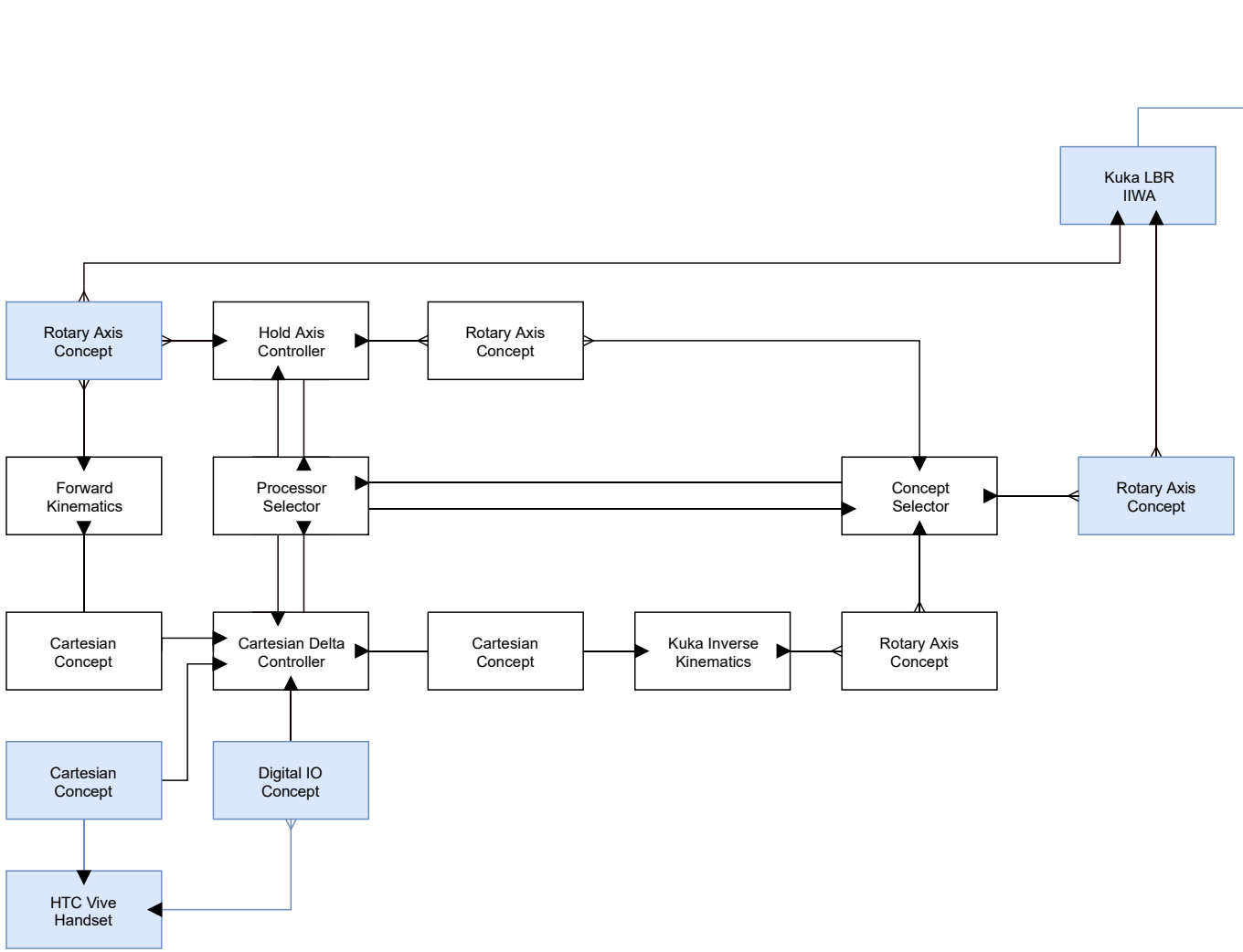
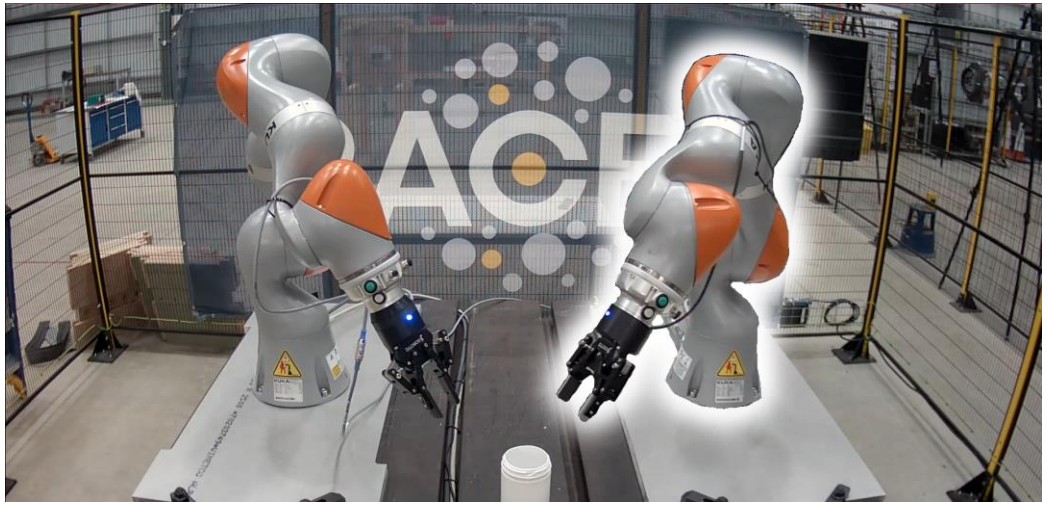
Example System Architecture

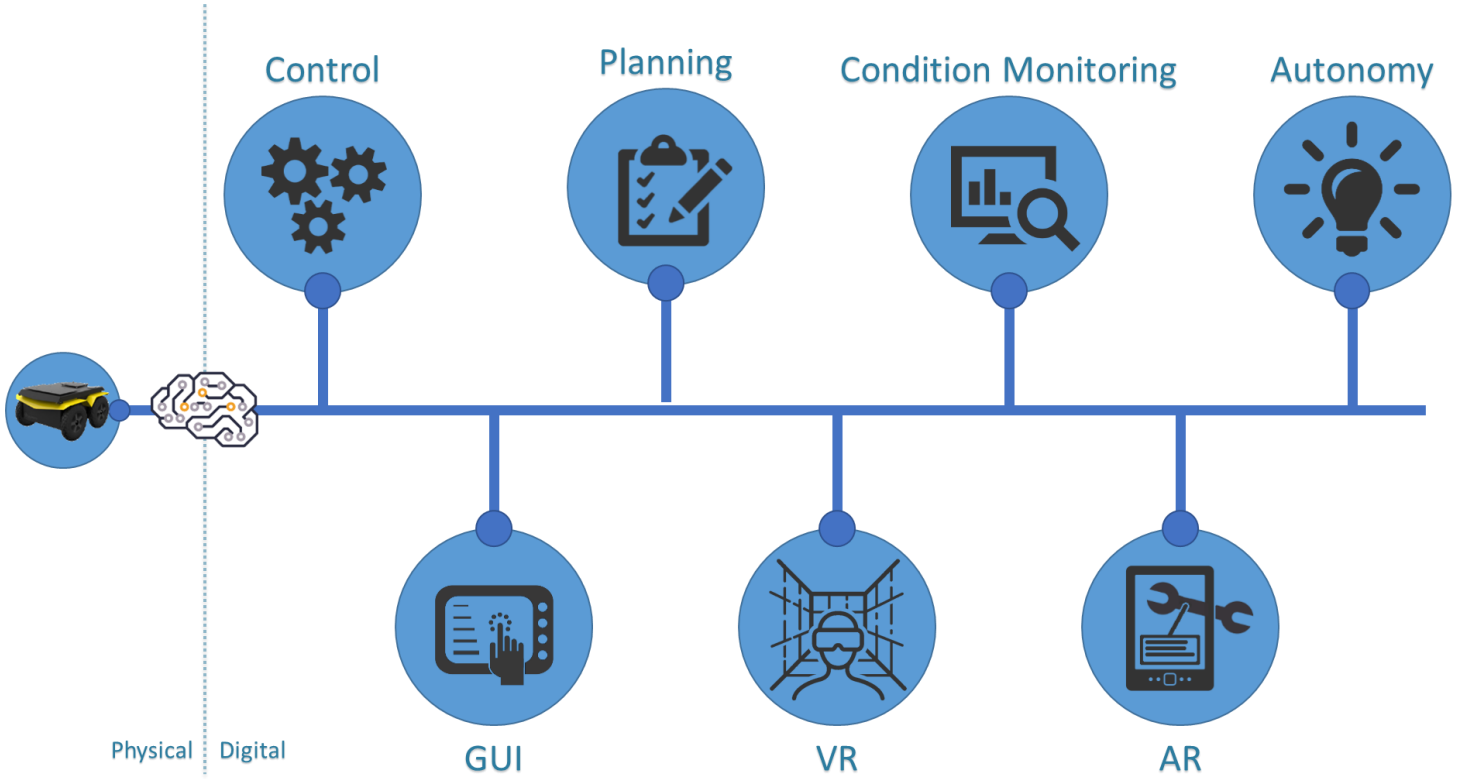




What tools have been developed, using CorteX?

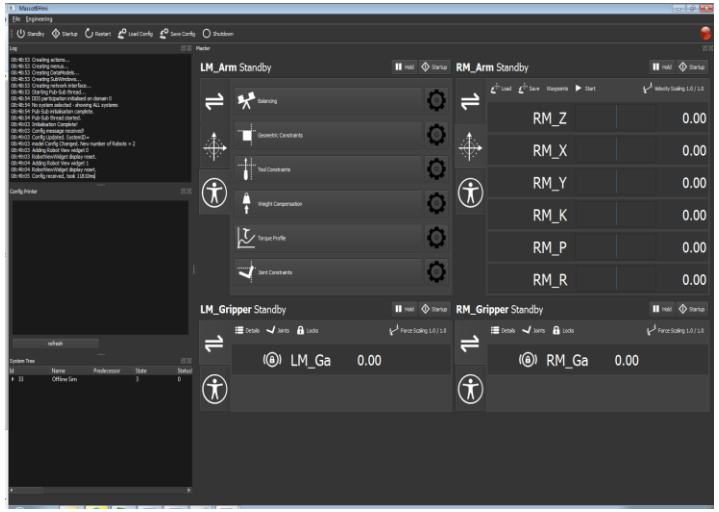
Examples:

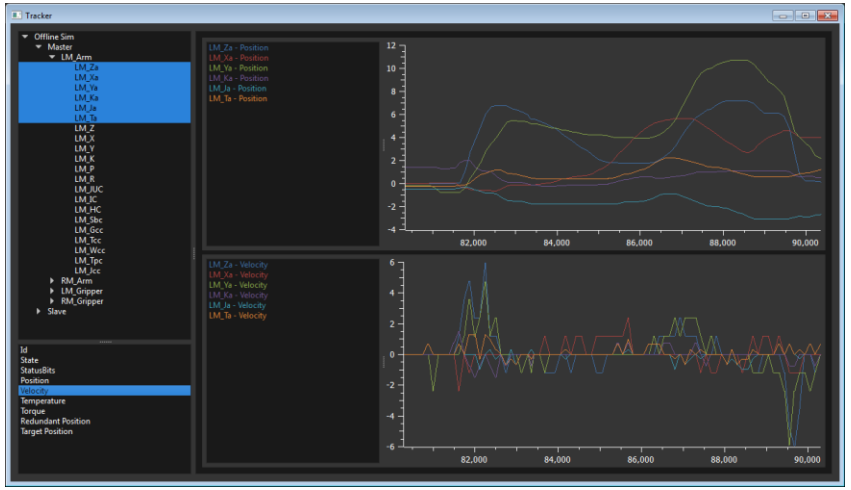
- Hardware interface
- Control
- GUI
- Planning
- VR / AR
- Condition monitoring
- AI / Autonomy
- Etc.

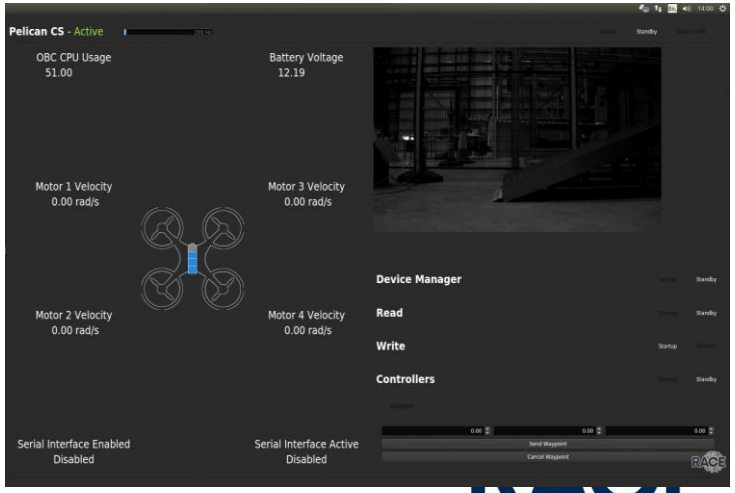


Model-driven, automatically generated GUIs

- Byproduct of self-description and standardized data representation.
- GUI only needs compiling, unit testing once
- Human Factors, Accessibility standards, look and feel consistent across whole facility
- Reduces training need
- Just one example of interoperable behavior and benefits





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Current & planned deployments

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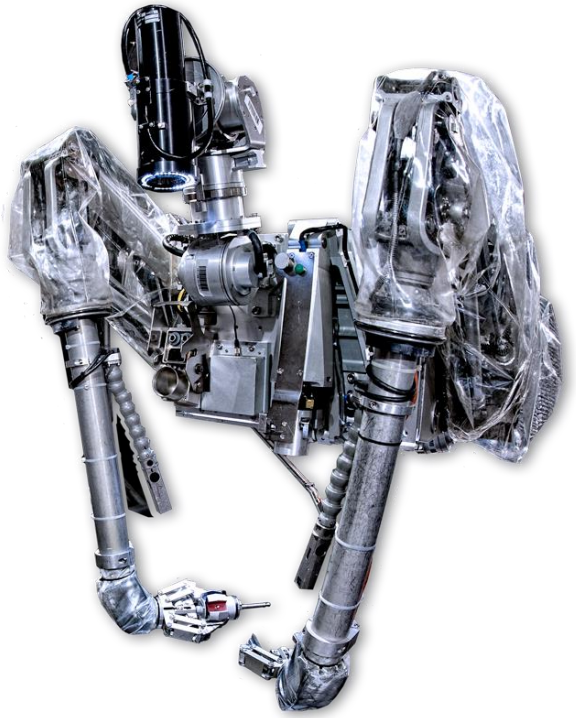
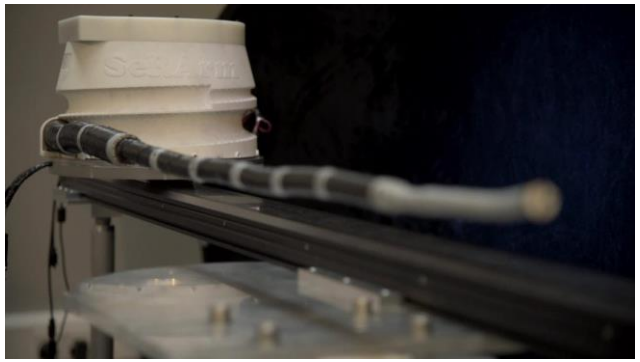
- 2x Integrated Innovation in Nuclear Decommissioning project teams
- 3x InnovateUK projects on maintenance, repair, decommissioning
- Joint European Torus remote maintenance systems
- European Spallation Source Active Cells Facility handling systems





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This software has the potential to reduce the cost to develop, integrate, and maintain robotic facilities in high-consequence environments.

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CorteX - Research Areas

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- Big data, lightweight methods
- Geometric data and sensor fusion
- HMI/GUI
- Multi-agent systems
- VR / AR
- AI / Autonomy
- Model-driven approaches?
- Verification (Modular? Run-time monitoring?)
- Cyber Security
- Distributed control
- Real-time analysis
- Scheduling and prioritisation
- Optimisation
- Modelling, representing, and propagating uncertainty
- Other applications

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Thank you!

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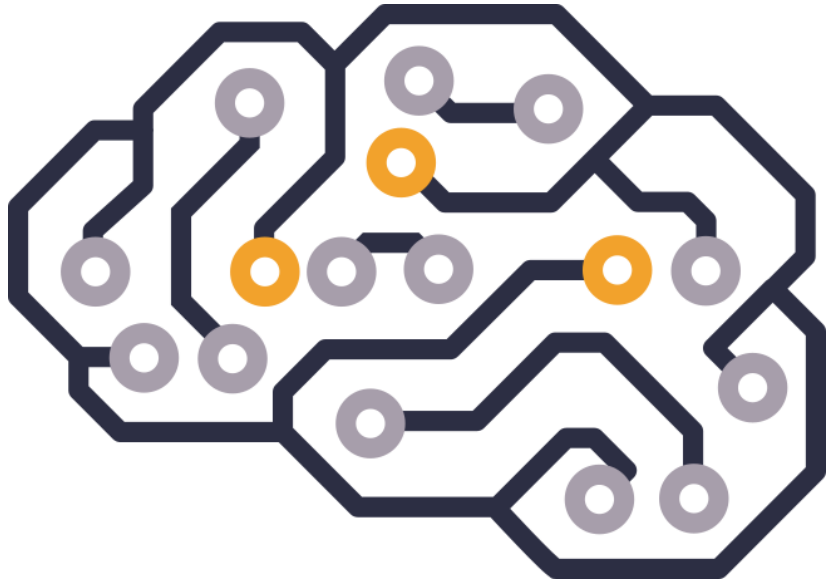

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