Software Engineering Trends in Robotics

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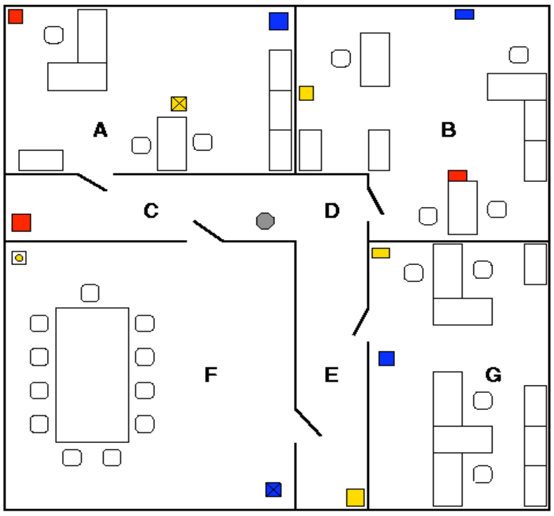
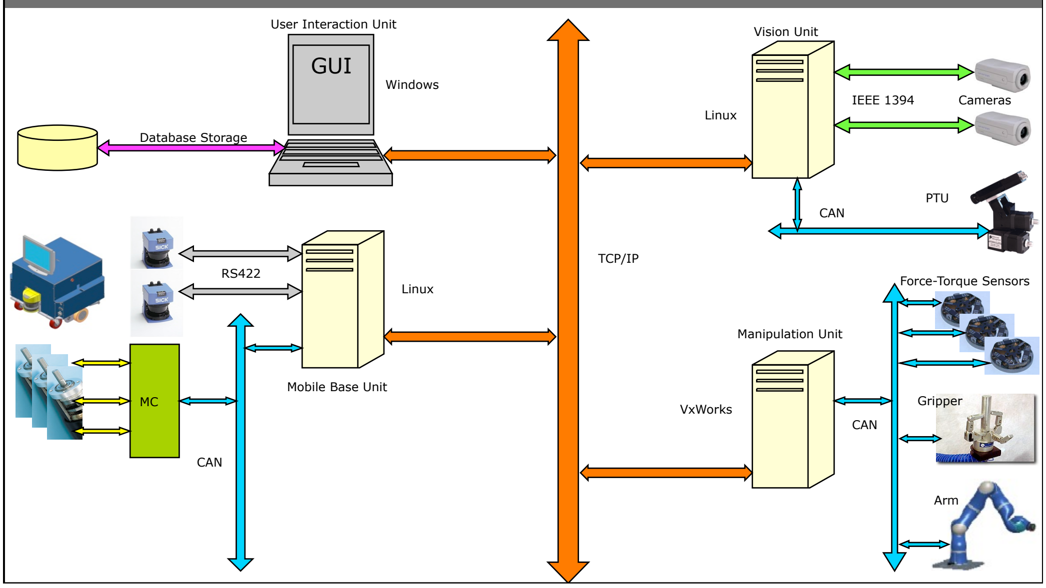
Use Case Scenario
Clear Up The Kitchen Table

- Indoor
- Rooms with furniture
- Mobility
- Task-relevant objects
- Object manipulation
- Spatial knowledge
- Failure-safe operation
- Fault tolerance

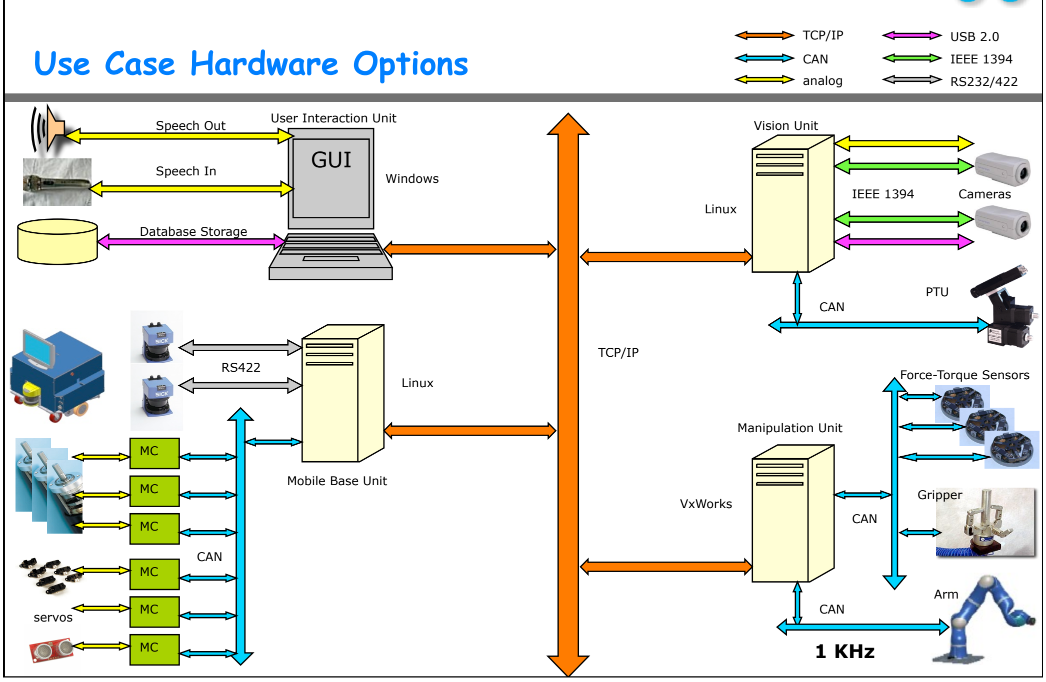
- Possibly also
  - Several rooms
  - Doors
  - Moving people
  - Moving objects



Use Case Hardware Platform



Use Case Hardware Options



Characteristics of the Robotics Domain

- Extremely heterogeneous hardware
- Inherently concurrent
- Inherently distributed
- Device dependent
- Stochastic properties of physical world
- Real-time constrained
- Resource constrained

- Currently not adequately supported by available
  - robot software architectures
  - robot software development environments

- Inadequate evaluation and assessment
- Mere demonstration character

Software for Autonomous Mobile Robots: Heterogeneity of Hardware

- Robots, robot teams, sensor networks are distributed system composed of very heterogeneous hardware
  - sensors:
    - bumpers, IRs, sonars, laser scanners, accelrometers, gyros, GPS, microphones, cameras, omnicams, stereoheads
  - actuators:
    - DC motors, steppers, servos, kickers, pan-tilts, arms, hands, legs, HDoF bodies, polymorphic systems
  - computational entities:
    - microcontrollers, embedded PCs, PDAs, notebooks, remote PCs
  - communication devices, mechanisms, and protocols:
    - I2C, serial, CAN, USB, UDP, TCP/IP, Firewire
- No plug and play!
- No configuration management!
- Heterogeneity grows over system lifetime!
- By-and-large, hardware and software maintenance for large robot teams and large embedded sensor networks must be considered unsolved

Software for Autonomous Mobile Robots: Distribution and Realtime Constraints

- Hardware and communication environment forces to deal with
  - Distributed programming concepts
    - Load balancing, multi-threading, concurrency, synchronization, signalling, event-driven activation, event ordering, ...
  - Communication protocols
    - Latency, timeouts, partial system failures, ...
  - GUI event loops

- Responsiveness to sensor- and actuator-initiated signals
  - Requires realtime or pseudo-realtime computing
  - Noisy sensors and actuators
  - Location dependency
  - Need for probabilistic models
  - Need for elaborate world models

Software for Autonomous Mobile Robots: Diversity of Software

- Roboticists use a wide diversity of often computationally intensive methods
  - Control theory
  - Computational geometry
  - Neural networks
  - Genetic algorithms and evolutionary methods
  - Reinforcement learning
  - Vision processing routines
  - AI planning techniques
  - Behavior systems
  - Probabilistic reasoning
  - Optimization techniques
  - Search techniques

- All these problems make software development for mobile robots very complex and error-prone

Programming Mobile Robots

- Responsiveness to sensor- and actuator-initiated signals requires multithreaded programming
- Realtime or pseudo-realtime computing
- Distribution, concurrency, reactivity, usability
- Communication, multi-threading, synchronization, event-driven activation, and GUI event loops
- Partial failures, latency, load balancing, signalling, event ordering, ...

- These problems
  - make software development in robotics complex and error-prone
  - hinder research
  - limit exchange of scientific results
  - jeopardize commercialization

What Makes The Problem Hard?

- No common architectures
- No common methods
- Hardware-dependency of developed code
- Missing abstractions
- No reusable components

A First Conclusion

- Any system,
  which takes away or limits the programmer's freedom
  to implement her architectural or computational ideas,
  is bound to fail.
- Any restrictions or commitments imposed by a system
  must be significantly outweighed by advantages gained.

Use Case Open Questions

- Mobile manipulation: integration of mobility and robot manipulation
- Challenge is the integration of multiple functionalities from both areas and finding solutions to new problems
- Use of pre-developed components, like arm, hand, base, etc., poses possibly hard integration issues
- In particular:
  - Different operating systems
  - Different communication protocols
  - Different inherent internal cycle times in functional modules
- Another hard problem: Detecting and handling failure situations

What Does Miro Offer?

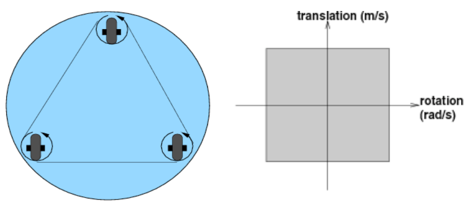
- Miro Device Layer
  - Clean, coherent object-oriented class interfaces
  - Available already for major parts
- Miro Communication and Configuration Layer
  - Various often-used communication patterns
  - Group communication via notify-multicast protocol
  - Extended XML-based configuration facilities
- Miro Service Layer
  - Unified network-transparent access to object services
  - Built-in facilities for data acquisition and logging
- Miro Framework Layer
  - Fine-grained control over complete visual processing via VIP
  - Flexible hierarchical reactive control via BAP
  - Particle filter-based self-localization

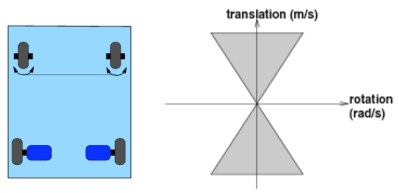
Example: Kinematics and Motion Interfaces

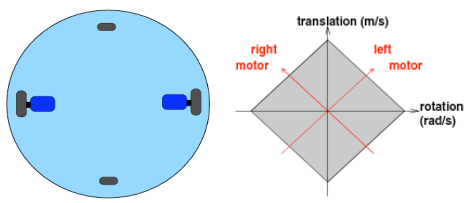
Different kinematics:

- Synchro drive
- Differential drive
- Ackermann steering

Different coverage of velocity space

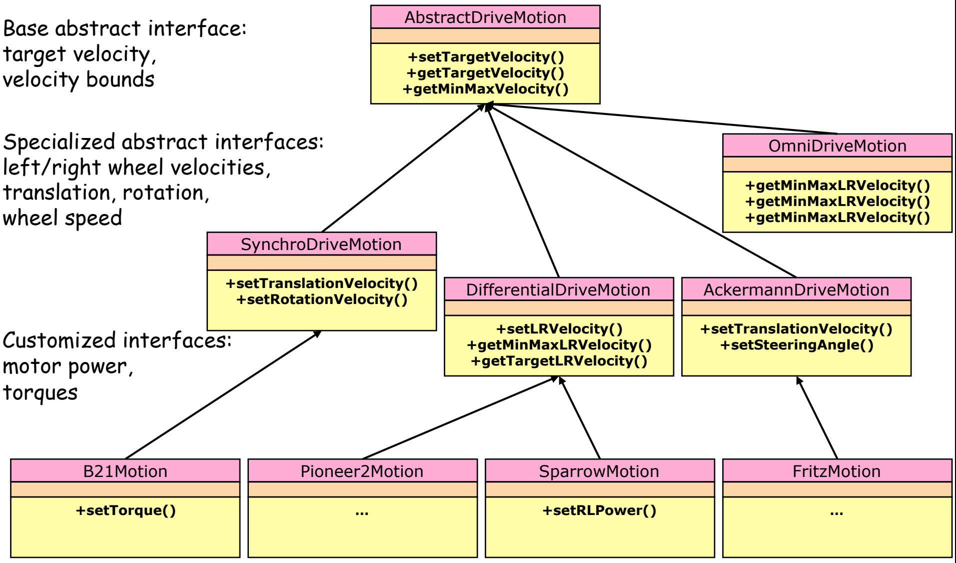






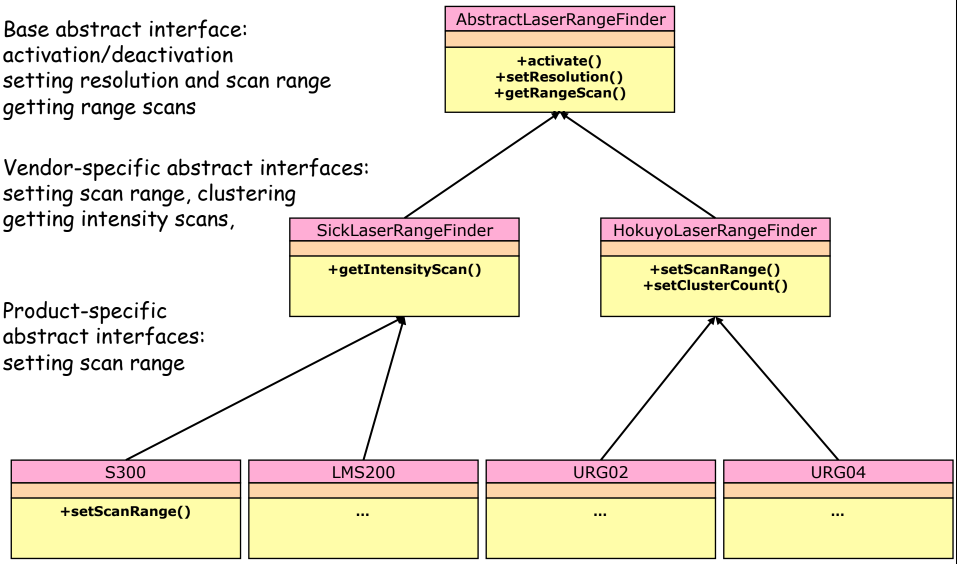
Abstract Actuator APIs Example: Drive Motion Services

- Base abstract interface:
  target velocity,
  velocity bounds
- Specialized abstract interfaces:
  left/right wheel velocities,
  translation, rotation,
  wheel speed
- Customized interfaces:
  motor power,
  torques



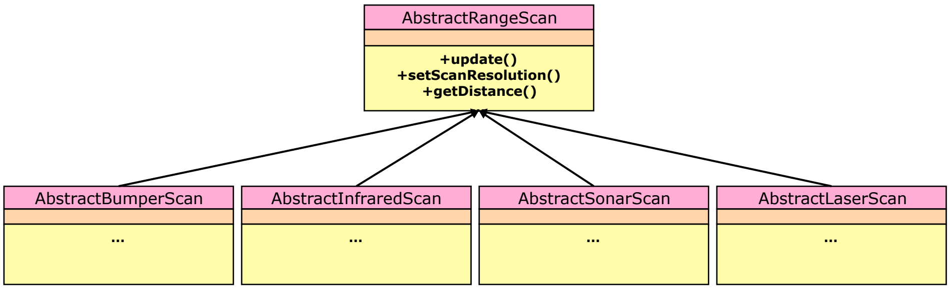
Abstract Sensor APIs Example: Laser Range Finder Services

- Base abstract interface:
  activation/deactivation
  setting resolution and scan range
  getting range scans
- Vendor-specific abstract interfaces:
  setting scan range, clustering
  getting intensity scans,
- Product-specific
  abstract interfaces:
  setting scan range

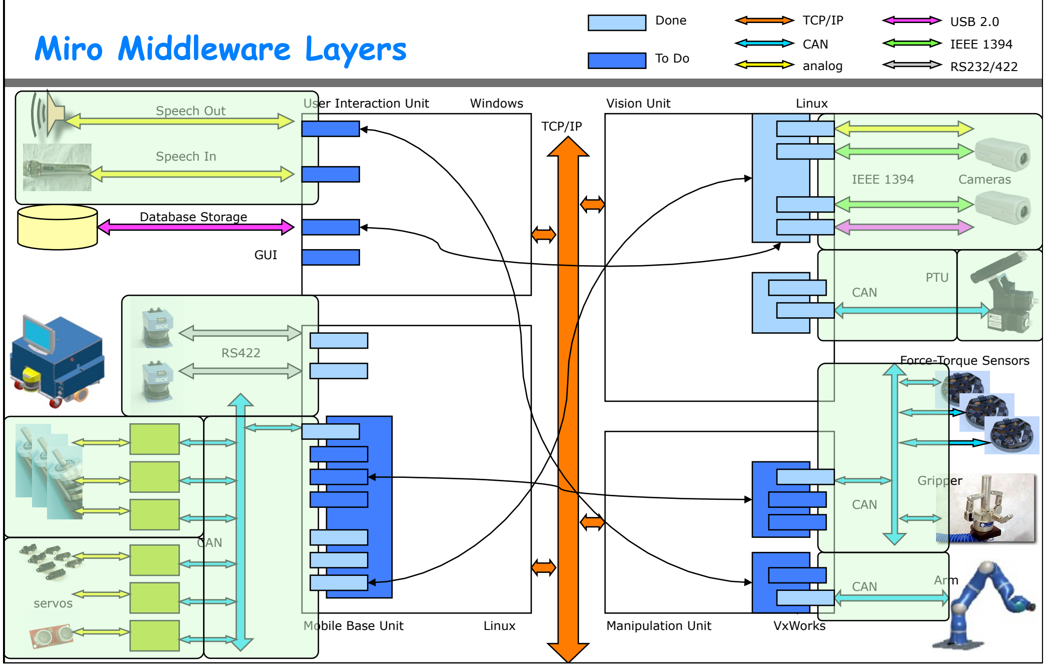


Abstract Data APIs Example: Range Scan Services

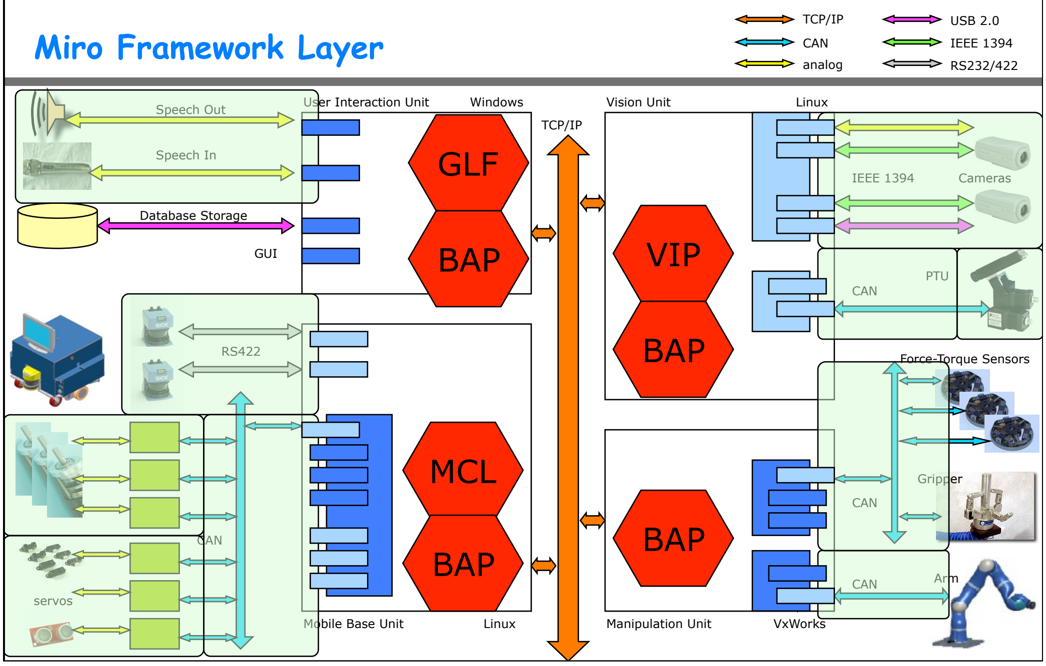
- Generalization for laser range finder, infrared, sonar, bumper scans
- Reference to specification of sensor layout
- Multiple modes of data publishing
- Multiple modes of data updating
- Permits for generic obstacle avoidance services



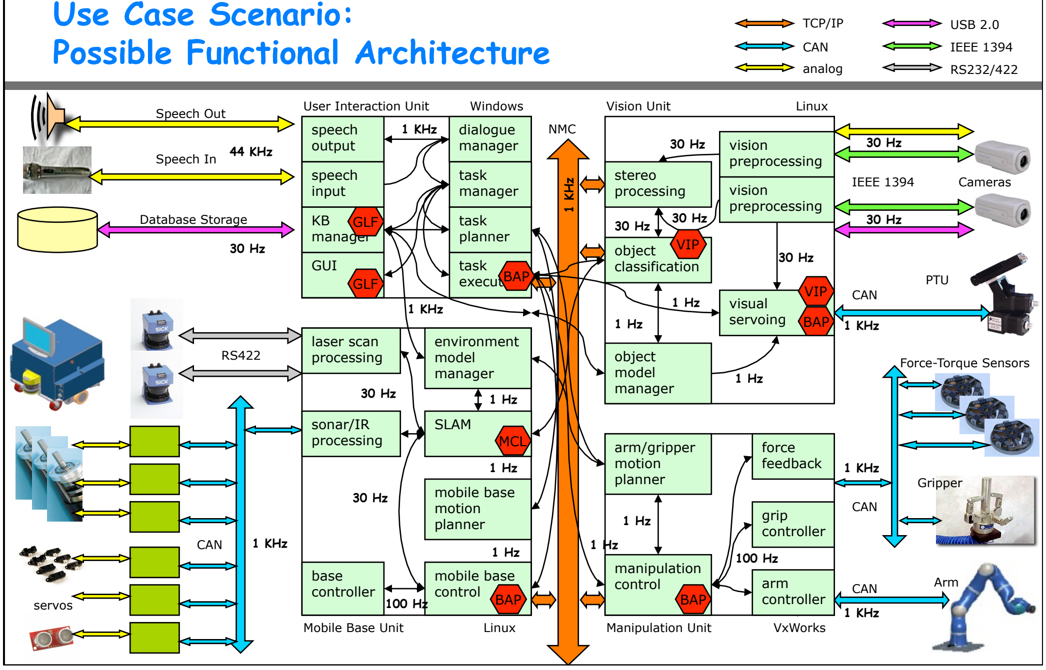
Miro Middleware Layers



Miro Framework Layer



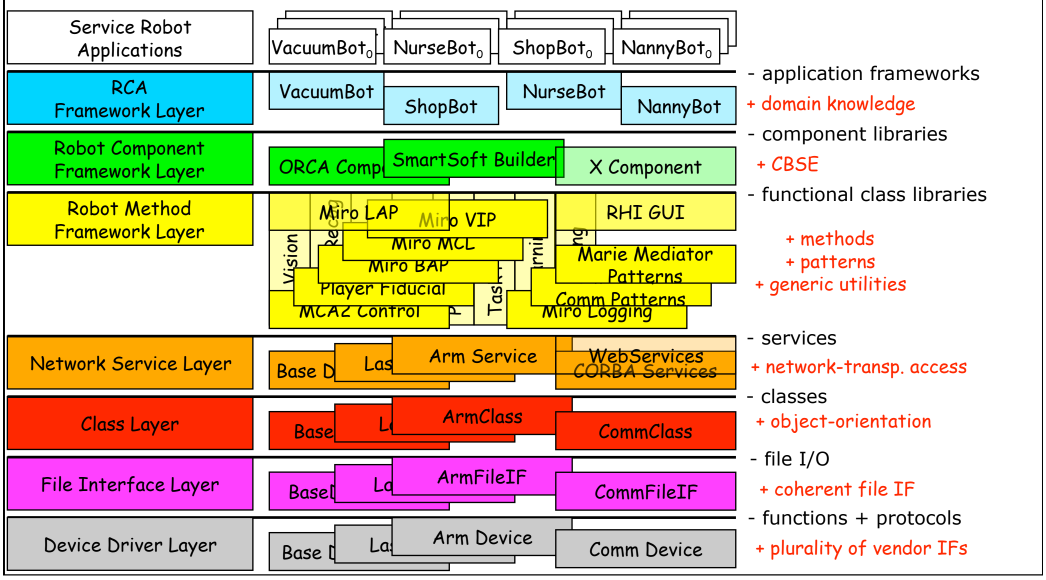
Use Case Scenario: Possible Functional Architecture



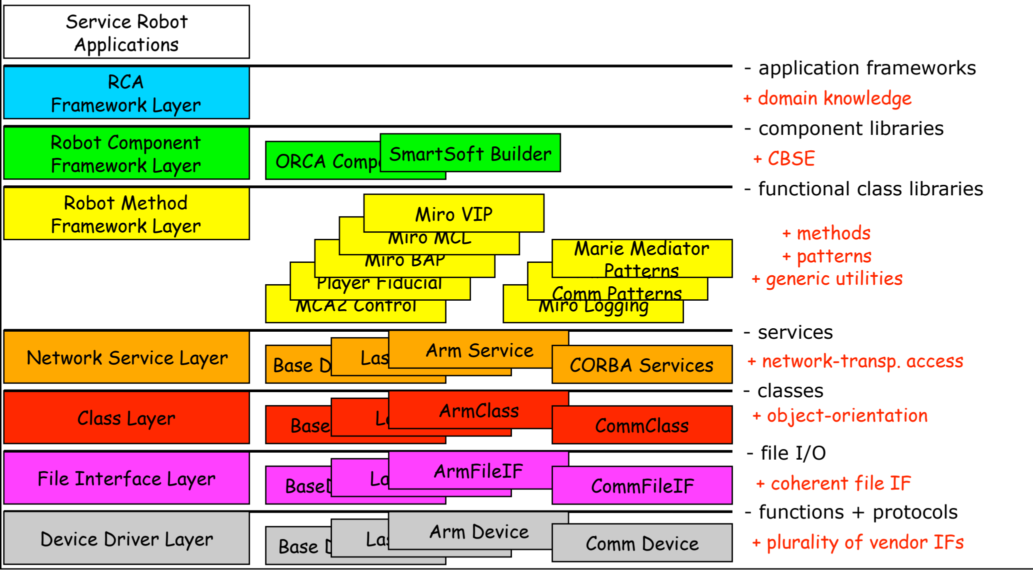
B-IT Tutorial in December 2005

- Player/Stage/Gazebo
- MCA2
- Smartsoft
- Miro
- Marie
- ORCA2

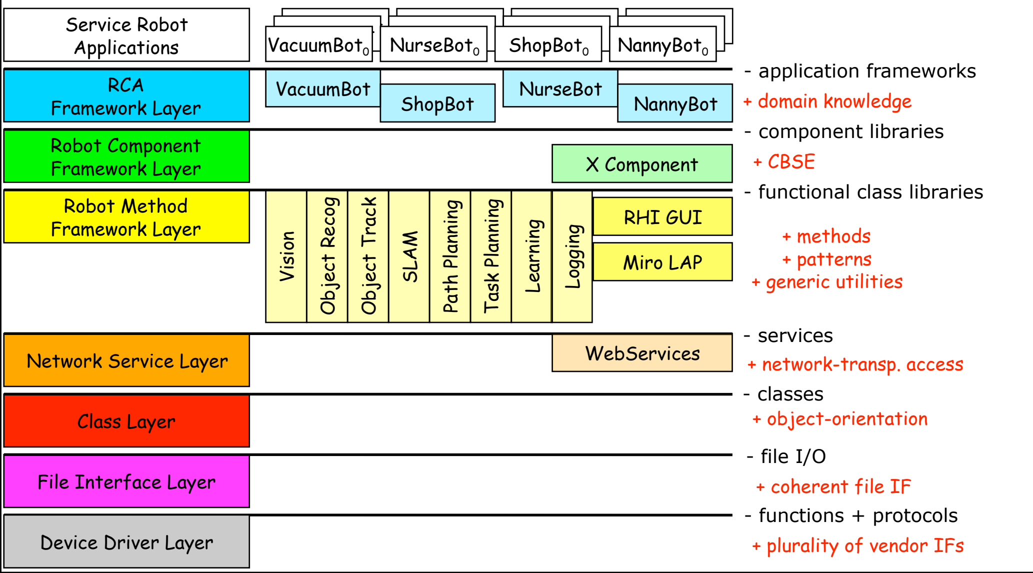
Synthesis by Functionality



Synthesis by Functionality (current)



Synthesis by Functionality (needed)

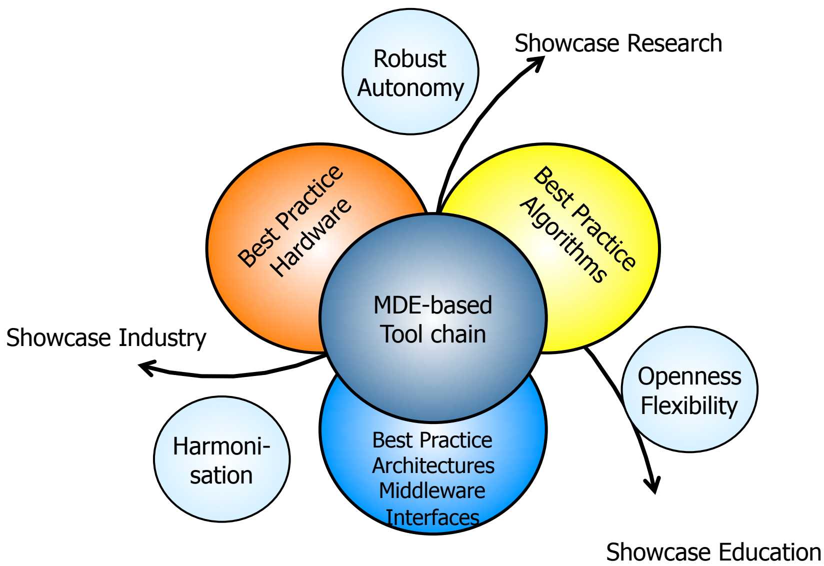


The Next Generation of Robotics Software Development

new developments yet to be fully appreciated by robotics
- agile software development
- software libraries of best practice algorithms
- model-based software engineering

cross-sectional topics
- harmonization for interoperability and portability
- robust autonomy
- openness

BRICS
Best Practice in Robotics



Consortium

KUKA

Fraunhofer IPA Institut Produktionstechnik und Automatisierung

GPS Gesellschaft für Produktionssysteme

NEOBOTIX

BLUEBOTICS Mobile Robots at your Service

University of Applied Sciences Bonn-Rhein-Sieg

University of Bergamo

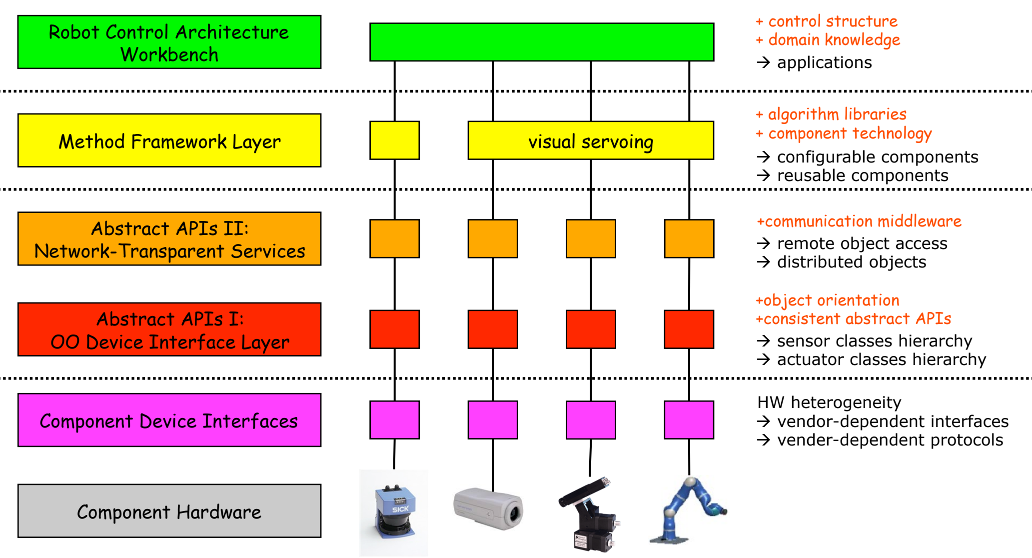
KATHOLIEKE UNIVERSITEIT LEUVEN

Universiteit Twente de ondernemende universiteit

WP2: Architecture, Interfaces, Middleware: Key Ideas and Concepts

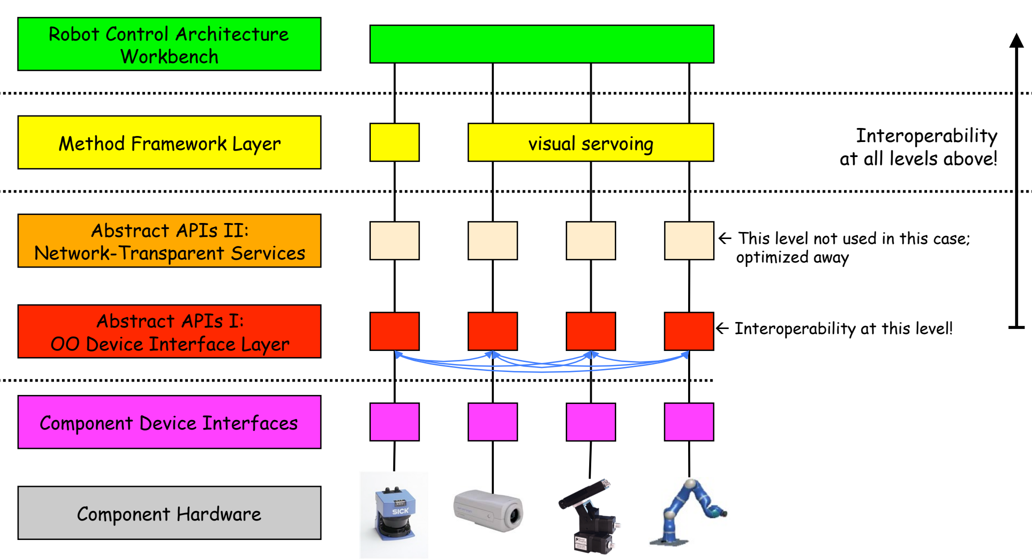
- Handling issues characteristic to robotics
  - Heterogeneous hardware (self-describing components etc.)
  - Distributed systems (communication frameworks, middleware)
  - Heterogeneous software (stratified interfaces, configuration, simulation)
- Making robots safe
  - Error handling (sw quality, monitoring, sw patterns)
  - Fault tolerance (plug-and-play, QoS, service level maintenance)
- Providing usable software engineering frameworks
  - Refactoring (… known solutions for quality: efficiency and robustness)
  - Software patterns (… apply known sw patterns and develop/identify new)
- Building architectures for robotic applications
  - Method frameworks (best practice of algorithms)
  - Component-based software construction (configuration)

BRICS Software Architecture Concept



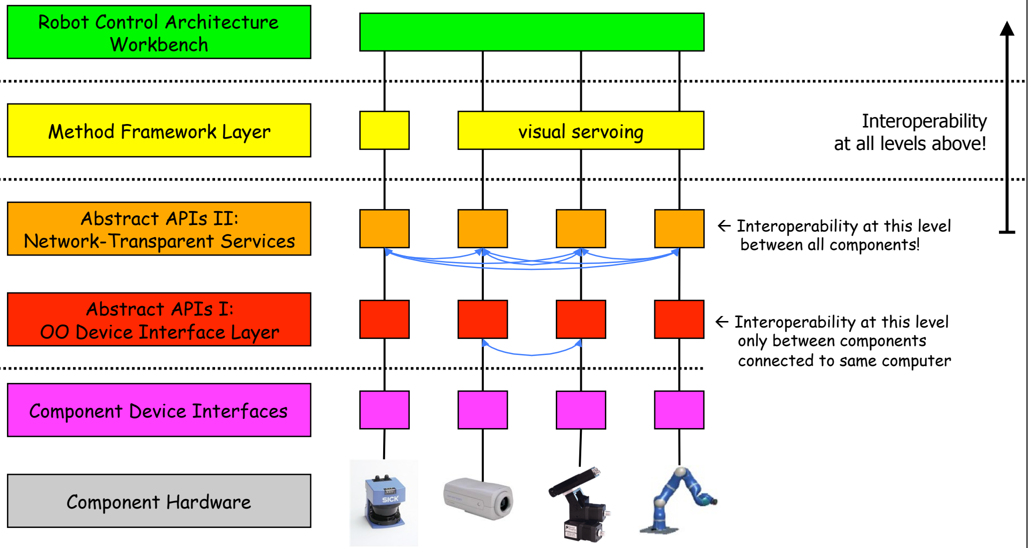
BRICS Interoperability

Simple case: all components connected to a single computer



BRICS Interoperability

Standard case: components connected to different computers



Conclusions

- software development for robotics is extremely difficult
- robotics is (partially) wakening up to software engineering issues
- some technology is around; using it is much better than not using it
- still a lot of work ahead of us
- BRICS project will address the pending issues
- outreach activities such as research camps allow community to get involved

- Thank your for your attention!