Object-Oriented Techniques in Robot Manipulator Control Software Development

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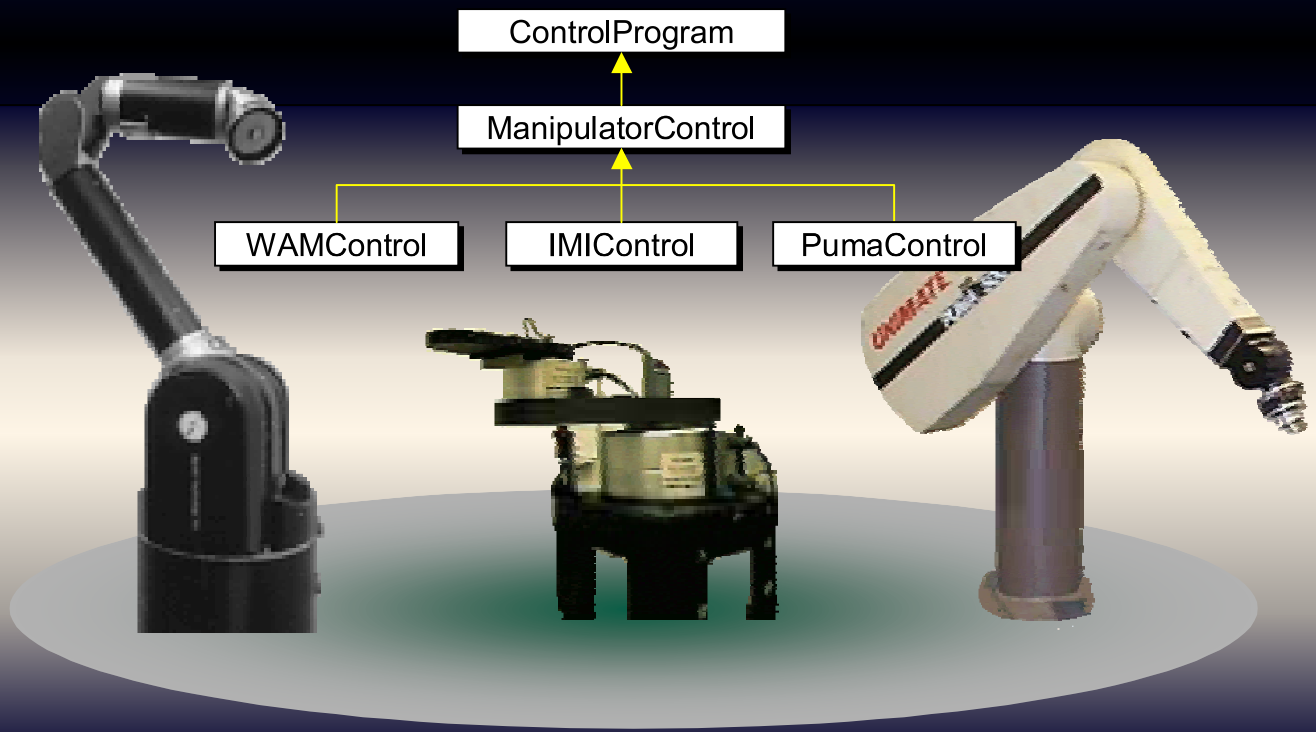
M. Loffler, D. Dawson, E. Zergeroglu, N. Costescu

Department of Electrical and Computer Engineering, Clemson University



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  - Review of Robot Control Platforms
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  - Overview
  - Object-Oriented Design
  - Run-Time Issues
  - QMotor
  - Class Design
  - GUI Components
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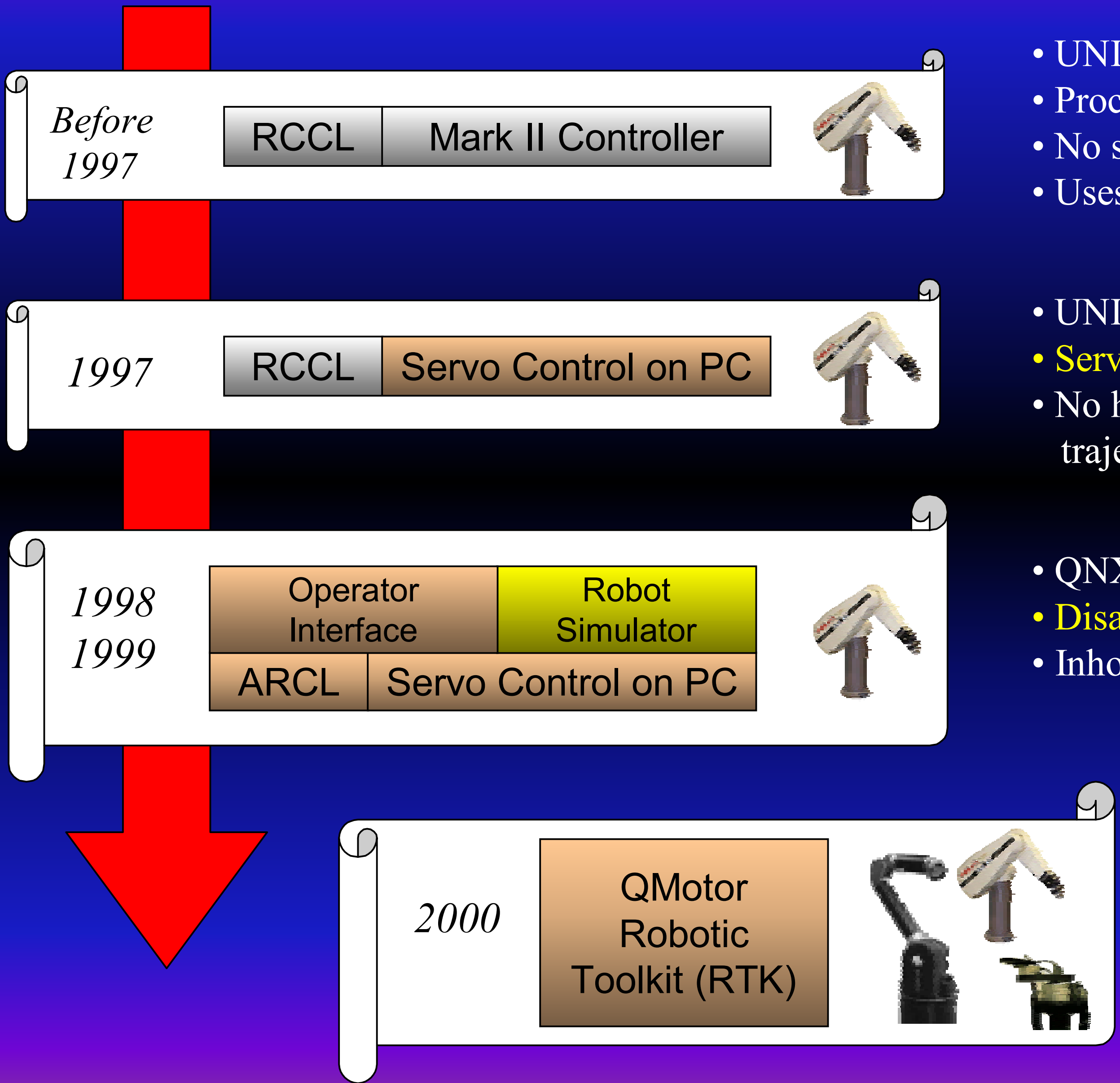
- Future Research

Introduction

- Robotic Control Systems at Clemson's CRB Group
- Review of Robot Control Platforms
- Focus of this Research

Introduction - Robotic Control Systems at CRB – towards Flexibility



- UNIX/workstation based
- Procedural
- No servo control flexibility
- Uses Puma 560

- UNIX/QNX/PC based
- Servo control flexibility
- No hard real-time in trajectory generation

- QNX/Windows/PC based
- Disassembly system
- Inhomogeneous components

- Modular
- Object-oriented
- Data logging/plotting
- Control tuning
- Puma, WAM, IMI

Introduction – Review of Robot Control Platforms

Robot Control Languages

VAL II

AML

V+

IRDATA

Problems:
- Proprietary
- Very limited flexibility
- Hardware integration

Platforms for Servo Control Development

MATLAB/Simulink

D-Space

RTWT

RTLT

WinCon

QMotor

Problems:
- Need to start at the lowest level

Simulink solutions:
- Limited flexibility
- Complex block diagrams
- High computational burden

Full Scale Robot Control Libraries

RCCL

OSCAR

ARCL

Problems:
- Too complex
- Limited flexibility
- Expensive hardware platforms required

Introduction – Focus of this Research

Modularity

- Independent components
- Easy to (re-) configure
- Easy Extension by adding new components
- Don't need to understand the whole platform for extensions

Flexibility

- Easy extension/modification
- Extend/modify on all system levels
- Reuse code

Real-Time Support

- Establish hard real-time
- No special hardware (e.g., DSP) required
- Debug real-time code
- Log and plot control signals
- Parameter tuning

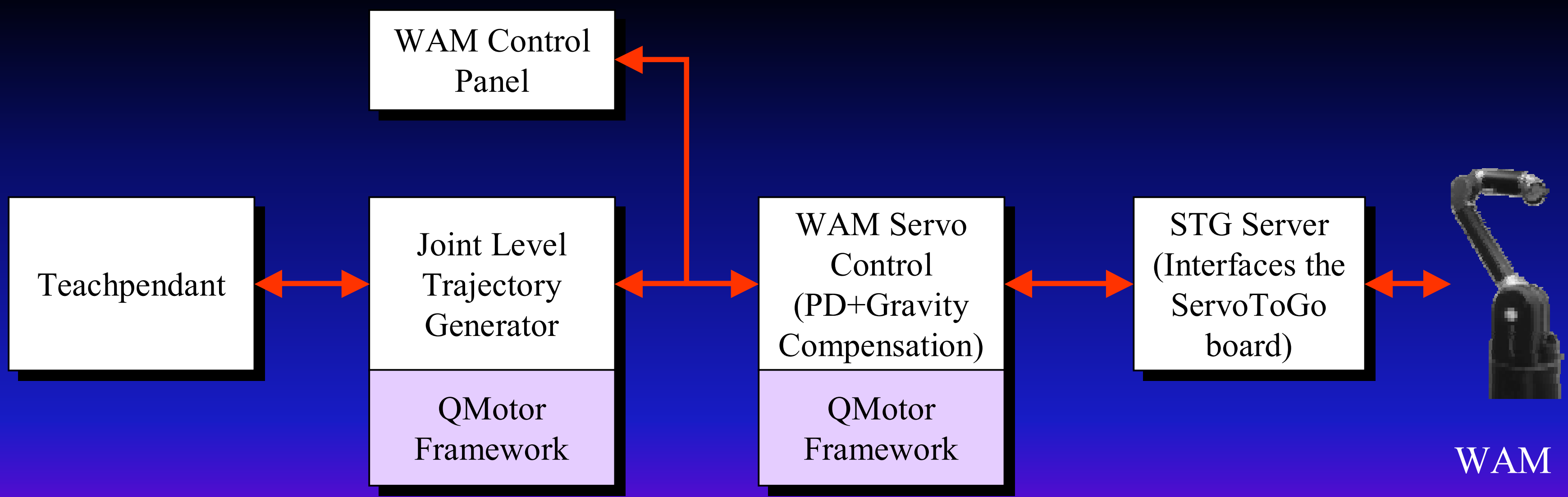
The QMotor Robotic Toolkit (RTK)

- Overview
- Object-Oriented Design
- Run-Time Issues
- QMotor
- Class Design
- GUI Components

QMotor RTK – Overview

The QMotor Robotic Toolkit

- Ready-to-execute programs and libraries
- Uses QMotor for real-time execution, logging, plotting and tuning
- Works only on the joint level
- Contains servo control, trajectory generator, teachpendant and utility programs



QMotor RTK – Object Oriented Design / Design in Classes

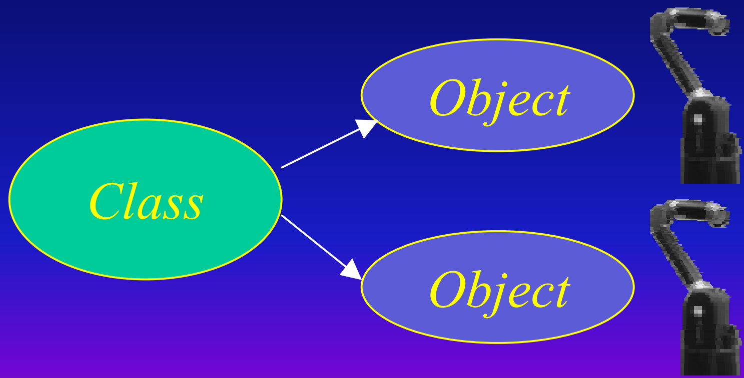
Data Representation
Current Position
Control Torques
Control Parameters
Etc.

Functions
Calculate control law
Determine the position
Enable arm power
Etc.

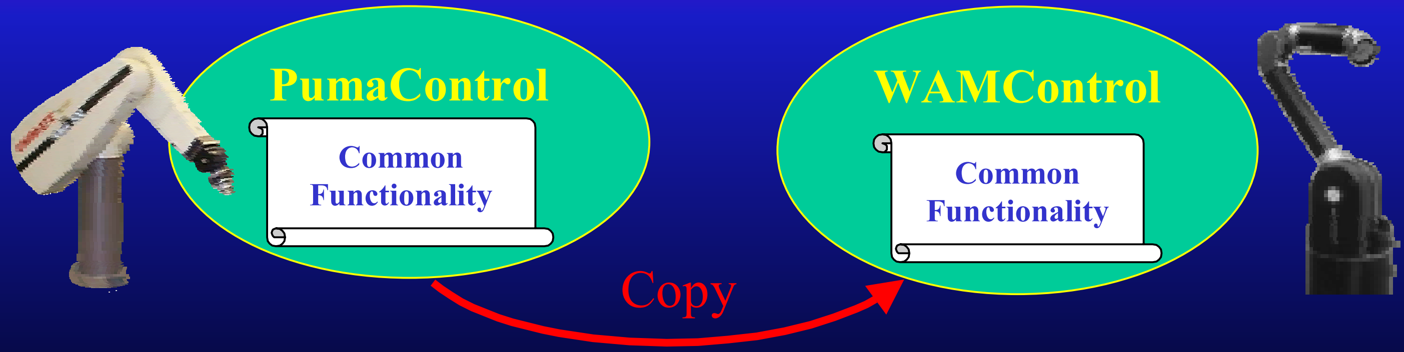
class WAMControl

Advantages:

- Intuitive modeling of the physical system
- Multiple physical objects through multiple software objects
- Inheritance



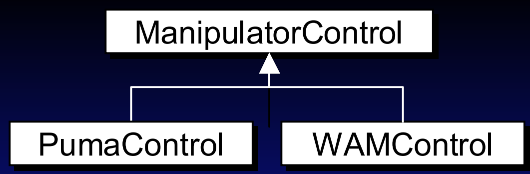
QMotor RTK – Object-Oriented Design / Inheritance

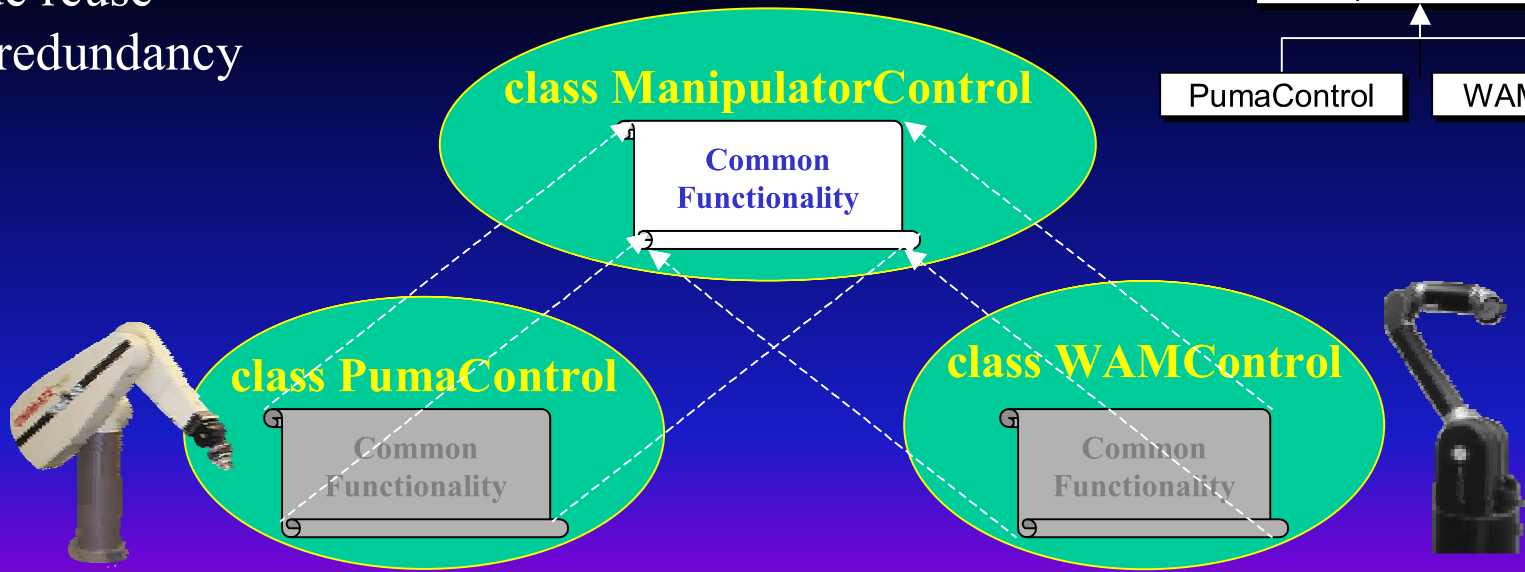


Object-Oriented Design

- Code reuse
- No redundancy

Class Hierarchies





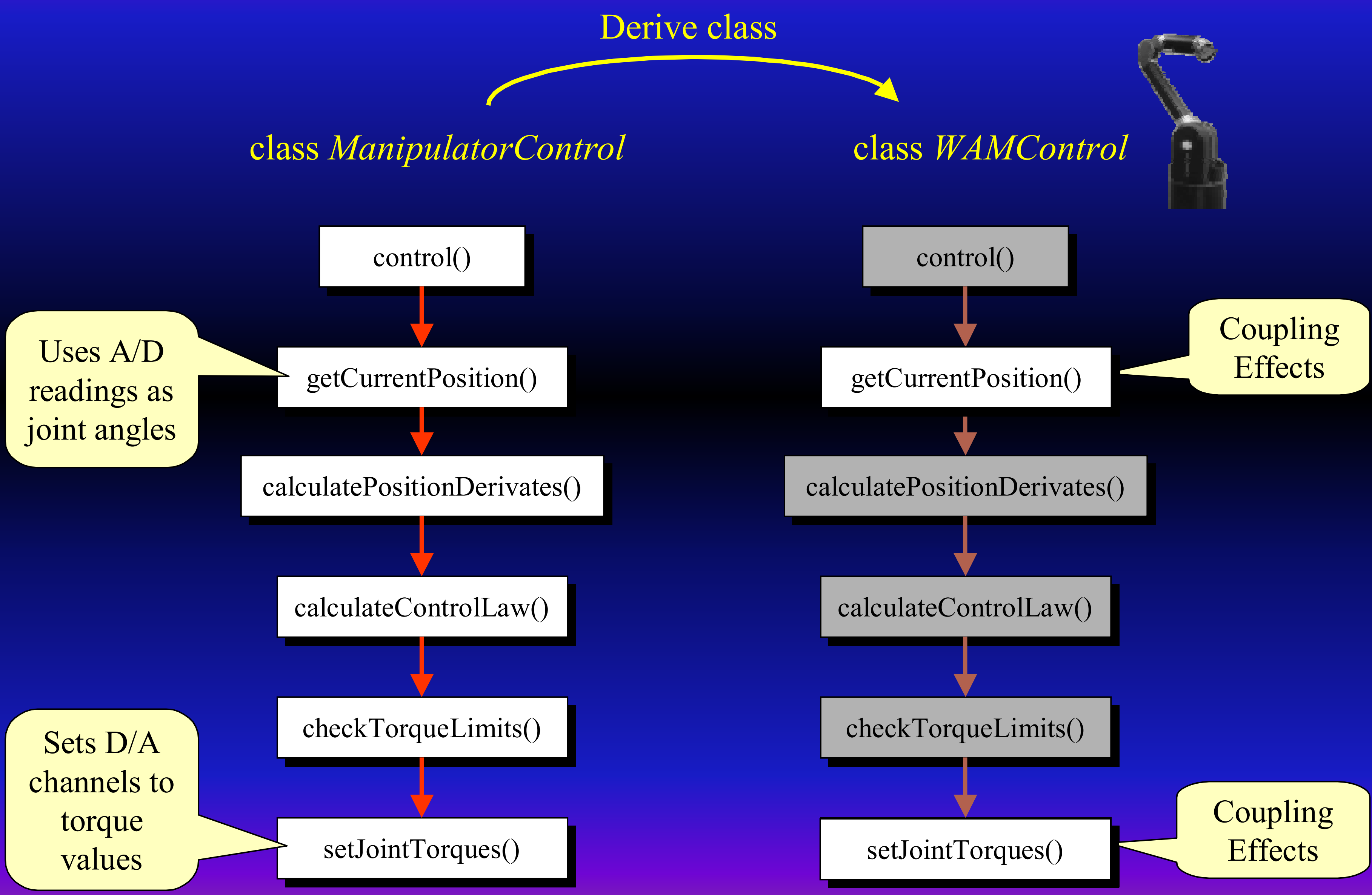
QMotor RTK – Object-Oriented Design / class ManipulatorControl

Common Functionality of all Manipulators

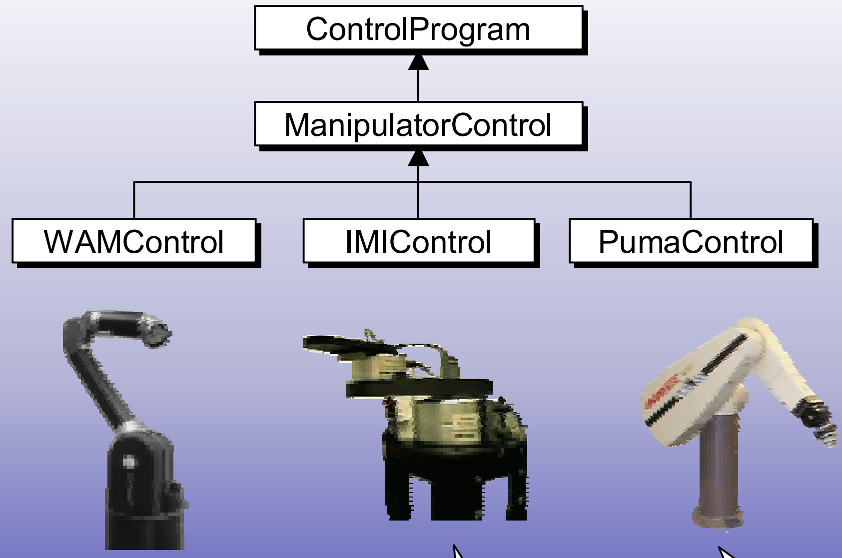
- Communication with the motion control board
- Setting output torques by setting voltages of the digital to analog converters (DACs)
- Position readings through encoders
- Enabling/disabling arm power by setting digital outputs
- PD position control
- Determining velocities and accelerations by backwards difference and filtering
- Communication with client tasks (*e.g.*, to receive a desired trajectory)
- Switching between control modes (*e.g.*, zero gravity mode/position control mode)
- Safety checks for joint and torque limits
- Manual calibration of the manipulator to a new (known) position
- Generation of a simple test mode trajectory



QMotor RTK – Object-Oriented Design / Deriving Manipulator Classes



Design Concepts – Specific Manipulator Control Classes



Specific WAM Functionality

- Automatic encoder calibration
- Joint coupling
- Gravity compensation
- Torque ripple compensation
- Damping control instead of disabling the arm power

Specific IMI Functionality

- No arm power control

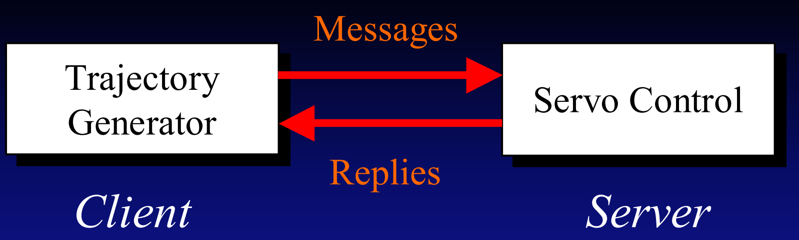
Specific Puma Functionality

- Automatic encoder calibration
- Joint coupling
- Gravity compensation

How can an object-oriented design execute on a real machine?

Concurrency
- Some components need to execute concurrently
- PC is fast enough (No need for special processors/hardware)
- Components run as separate programs
  (Easy reconfiguration)

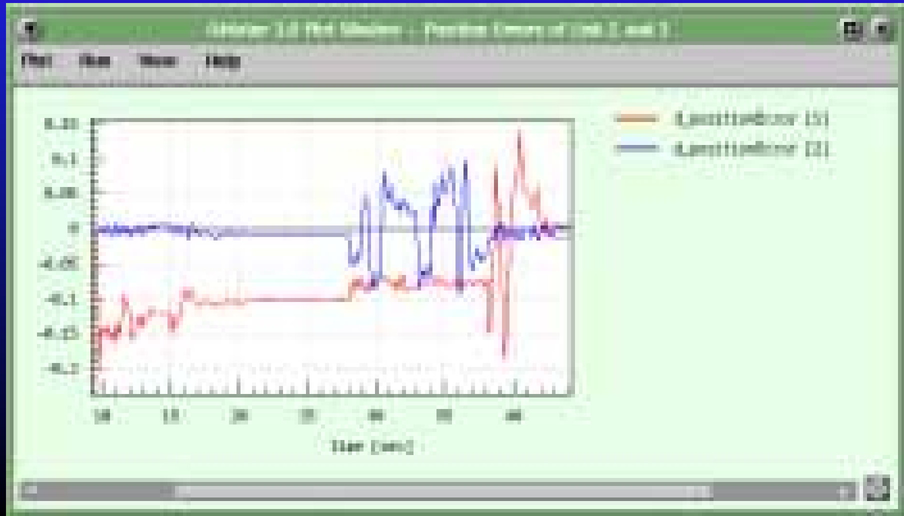
Communication
- Client/Server architecture
- Generic components



Real-Time Performance
- Need Real-Time Operating System -> QNX4
- C++ overhead can be neglected
- Need to be careful with dynamic memory allocation
- QMotor for control parameter tuning and data logging/plotting

The QMotor Graphical User Interface

- Provides an intuitive user interface
- Provides flexible real-time data plotting
- Provides control tuning



Plot Window

Main Window

Control Parameter Window

QMotor RTK – GUI Components

Manipulator Control Panel

Manual Move Utility

Teachpendant

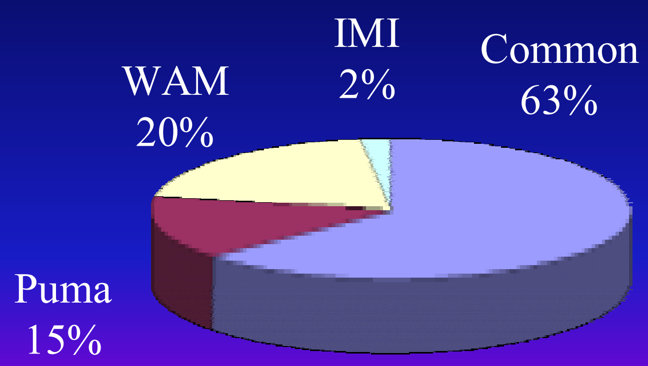
Conclusions

- Concluding Remarks
- Future Research

QMotor RTK – Conclusions

The QMotor Robotic Toolkit

- Lightweight modular platform, entirely implemented as PC software
- Object-oriented homogeneous design allows code reuse and easier extension for new hardware and new algorithms
- Addresses the issues of concurrency and real-time
- Data logging, control tuning and plotting from the QMotor GUI
- GUI components (Teachpendant, control panels)



Code Reuse

- 63% of the system is independent of the manipulator type, i.e., it can be reused for new manipulators
- Common code is well tested
- Implementation of new manipulators is very quick

QMotor RTK – Future Research

Disadvantages of the QMotor Robotic Toolkit

- Does not work in Cartesian space
- No 3D robot simulator
- Startup/Shutdown inconvenient with many components