Advanced Techniques for Mobile Robotics

Robot Software Architectures

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How to Program a Robot

- Robots are rather complex systems
- Often, a large set of individual capabilities is needed
- Flexible composition of different capabilities for different tasks

In this lecture, we discuss:

- What are important aspects of a robot architecture?
- What are good design decisions?

Discussion

- **What do you think is important?**

- Consider you want to build your own robot control software. What are relevant design decisions for that software?

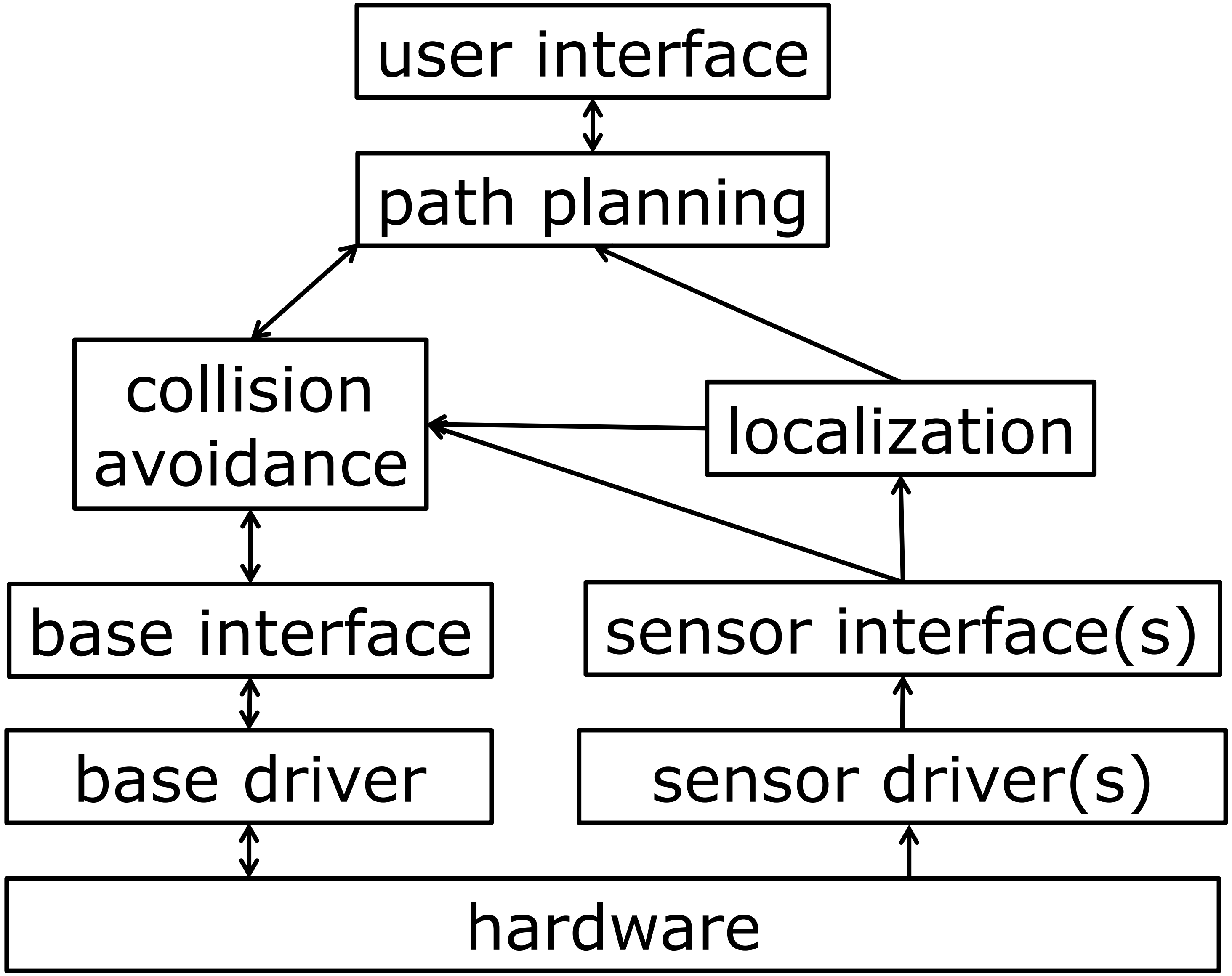
Requirements from a Academic Perspective

- Support for multiple components
- Communication between components
- Easy way to write own components
- Possibility to replace individual components
- Easy to extend
- Means for data logging and debugging
- Support for decentralized components

Desired Features from a Academic Perspective

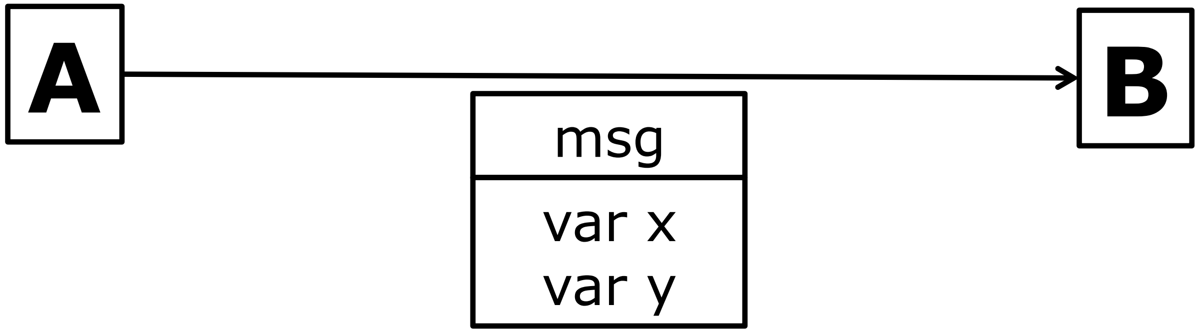
- Robustness
- Hardware abstractions
- Open access (ideal case: open source)
- Hardware/OS independent
- Means for time stamping
- Means for visualization
- …

Example

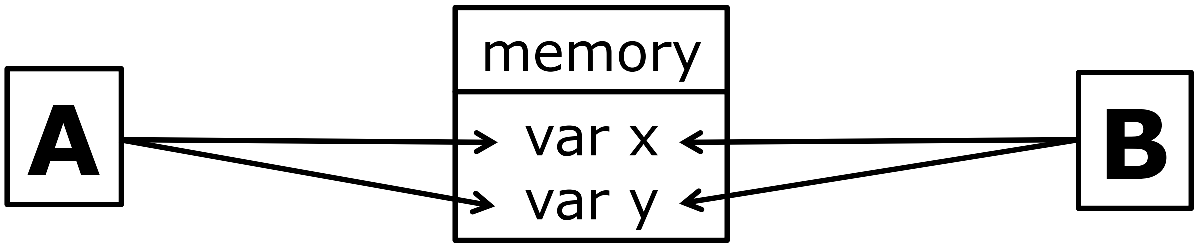

user interface
path planning
collision avoidance
localization
base interface
sensor interface(s)
base driver
sensor driver(s)
hardware

Communication Examples

- Message-based systems



- Direct (shared) memory access



Forms of Communication

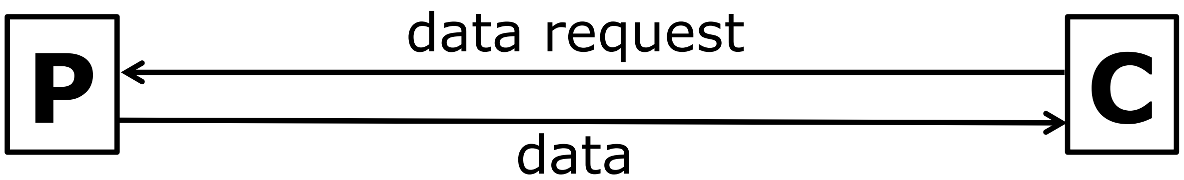
- Push
- Pull
- Publish/Subscribe
- Publish to blackboard

Push

- One-way communication
- Send as the information is generated by the producer P

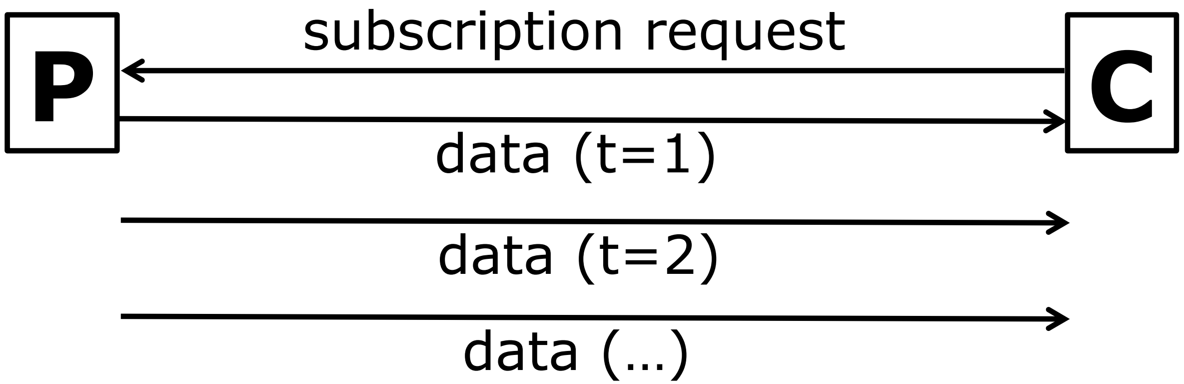
Pull

- Data is delivered upon request by the consumer C
- Useful if the consumer C controls the process and the data is not required at high frequency



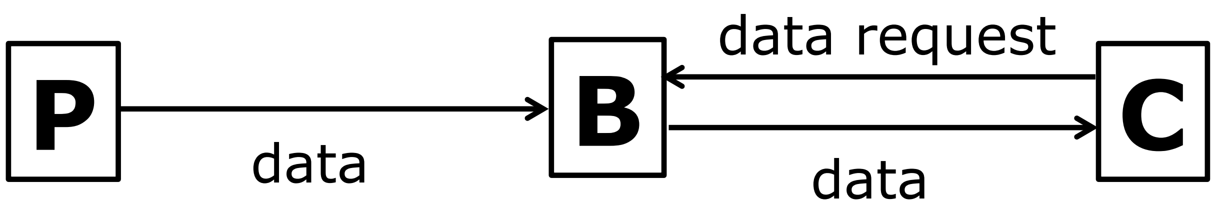
Publish/Subscribe

- The consumer C requests a subscription for the data by the producer P
- The producer P sends the subscribed data as it is generated to C
- Data generated according to a trigger (e.g., sensor data, pose corrections, …)



Publish to Blackboard

- The producer P send data to a blackboard
- A consumer C pulls data from the blackboard B
- Only the last instance of the data is stored in the blackboard B
- New data from P overrides previously sent data



Example: Laser Range Sensor

- Driver for the LRF reads the data from the hardware device (serial, USB, …)
- LRF driver offers a subscription to the topic “laser data”
- The localization module subscribes to the topic “laser data”
- The LRF driver will send every new laser range information to the localization module

Communication Infrastructure

- A communication infrastructure/robotic middleware is needed that provides such forms of communication
- There exists a large set of such infrastructures (not only for robotics)

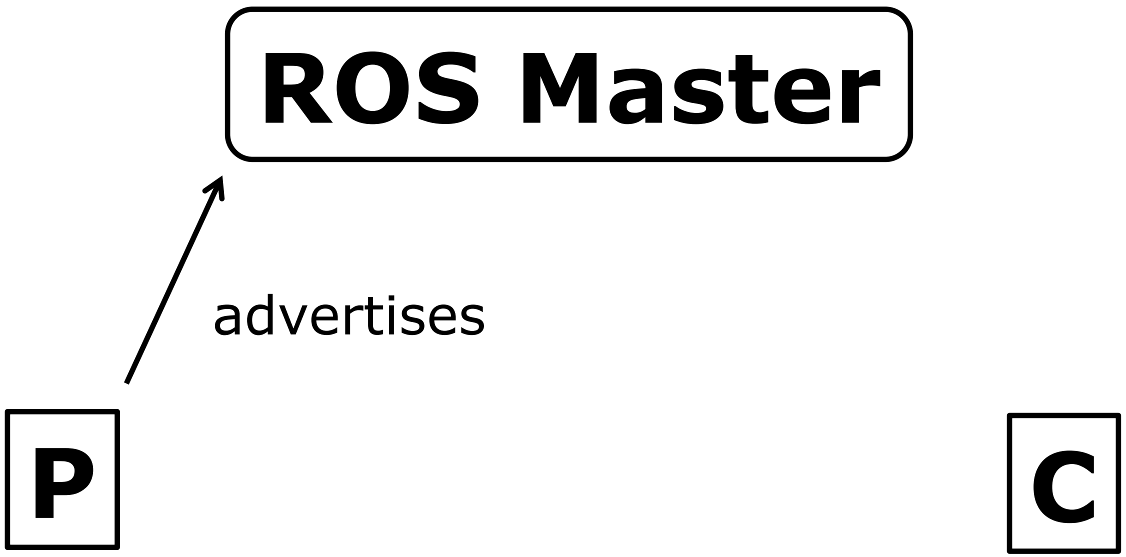
Examples (used in robotics)

- IPC by Reid Simmons (used in Carmen)
- MOOSDB by Paul Newman
- ROS-Master by Willow Garage
- ...

IPC, MOOS, ROS, and Friends

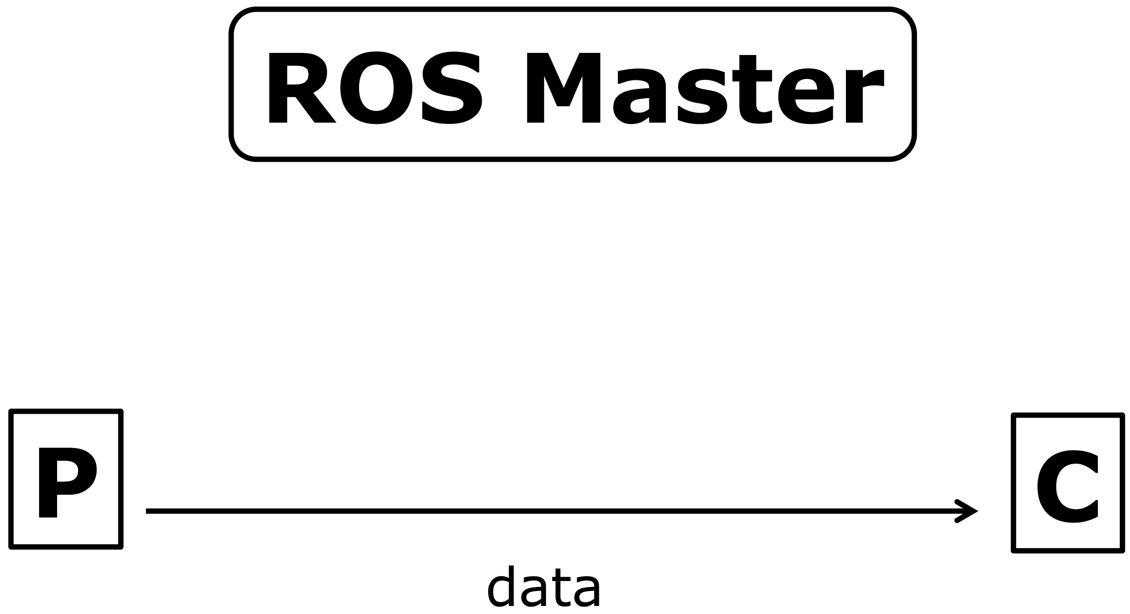
- Are created for easy data exchange
- Communication within and among processes (“programs”)
- Transparent network support
- Designed for “friendly environments”

ROS Master

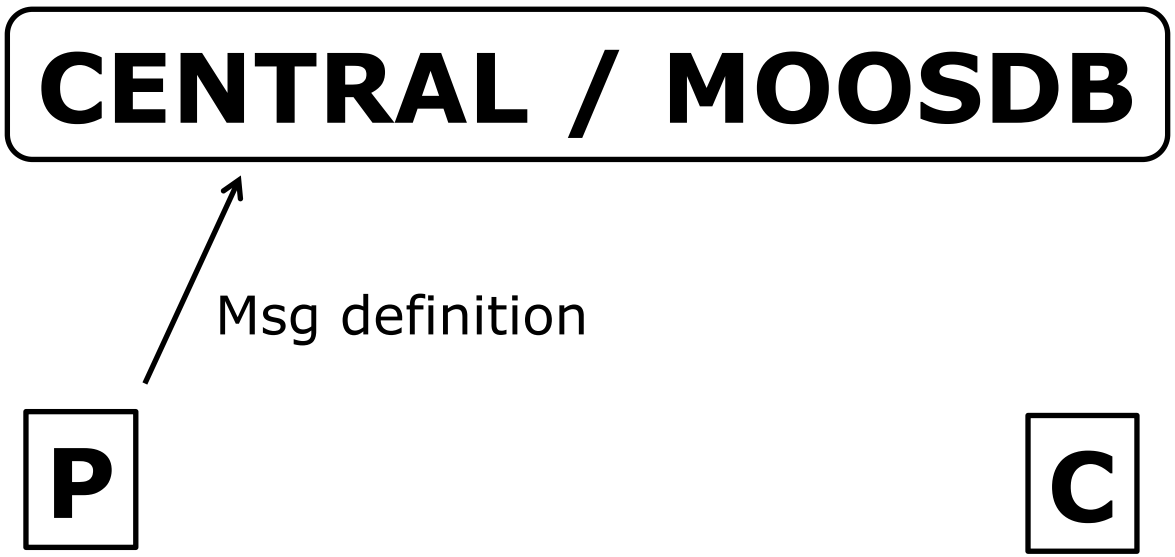


ROS Master

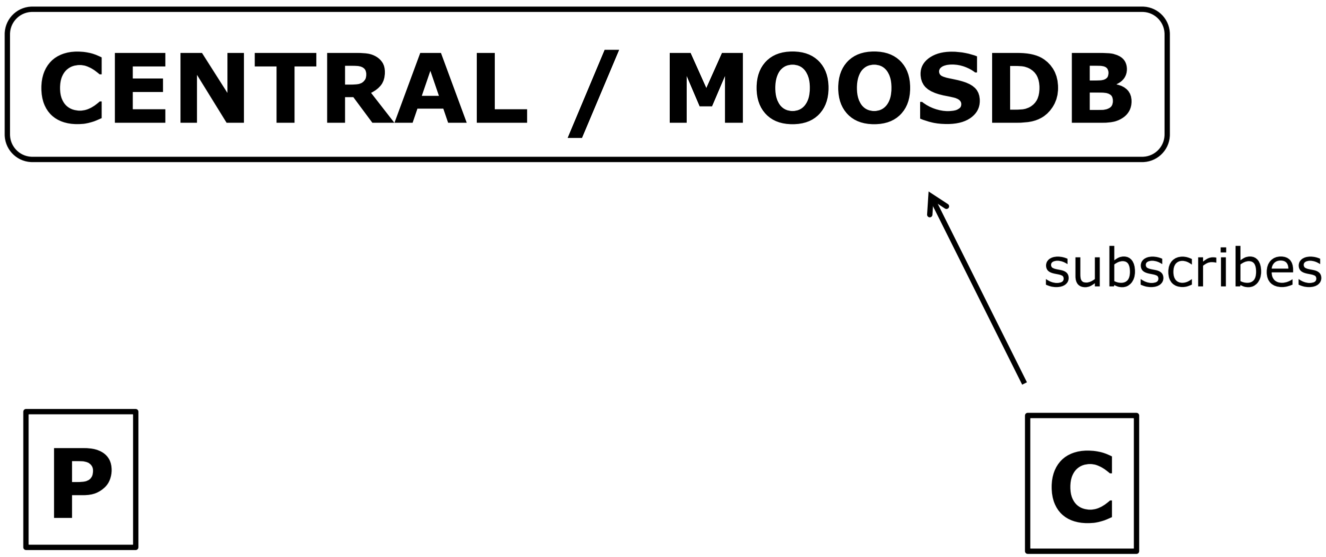
ROS Master



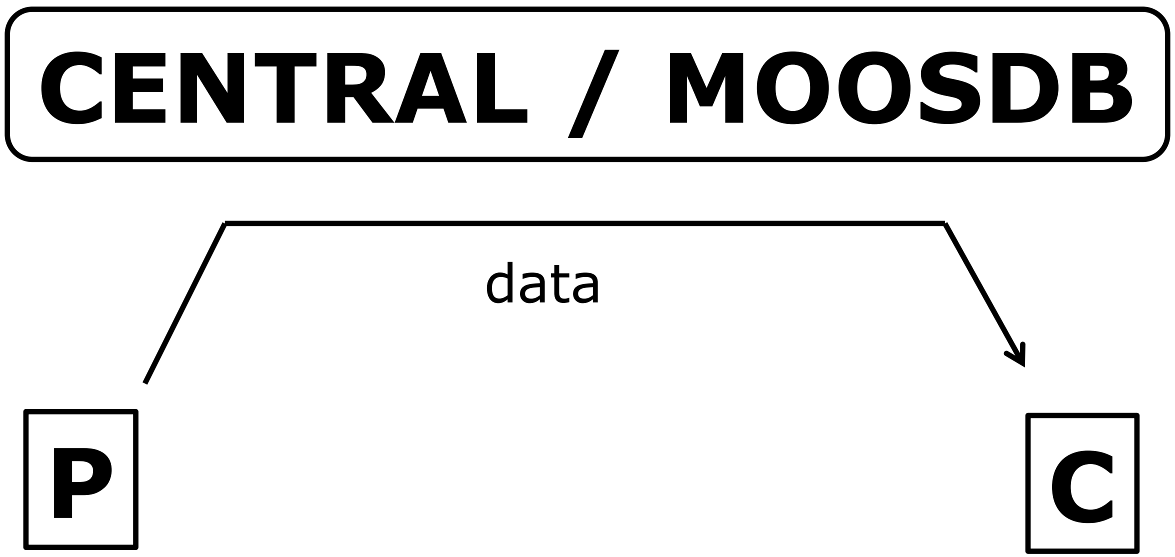
IPC Central & MOOSDB



IPC Central & MOOSDB



IPC Central & MOOSDB



Messages Through the Central

- **Discuss:** pros and cons

Messages Through the Central

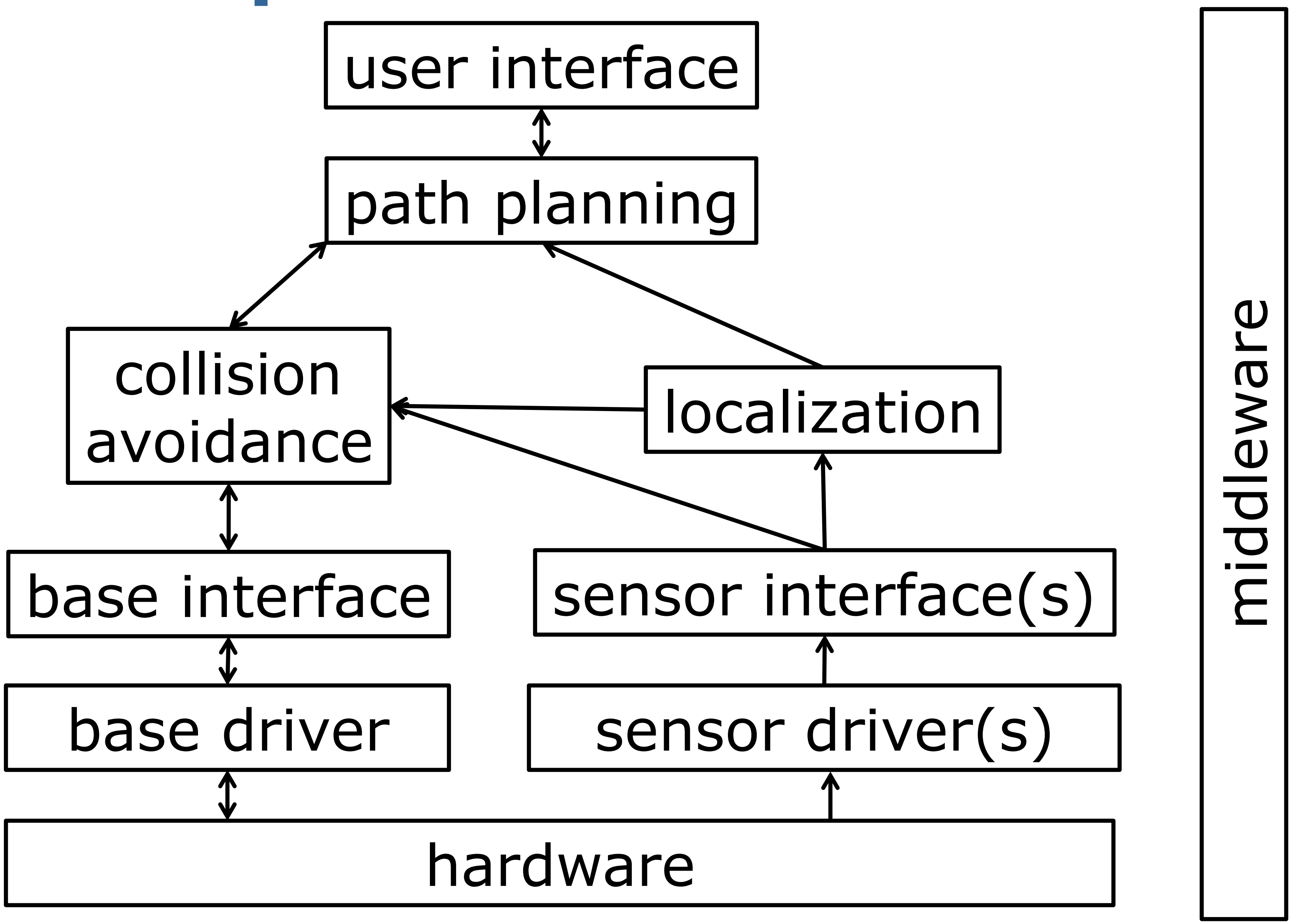
Pro

- Better control over message flow
- Transparent logging (time-stamping)
- No dead processes
- Centralized “health monitoring”

Con

- Slower/bigger delays
- Higher network traffic in decentralized systems

Example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sensor driver(s)
hardware
middleware

Other Differences

- Need to share header files
- Typed vs. non-typed messages
- Binary data vs. human readable strings
- Platform/OS independence
- Time synchronization
- …

Messages for Communication

- Each module provides a list of messages it sends (e.g., via publish) or wants to receive (via pull)
- This list of messages is the only way of communication (black box)

- Example:

Carmen
Robot Navigation Toolkit

Message Example in Carmen

A message definition:

```
typedef struct {
  double x, y, theta;
  double tv, rv;
  double acceleration;
  double timestamp;
  char *host;
} carmen_base_odometry_message;
```

A helper function to subscribe the message:

```
void
carmen_base_subscribe_odometry_message(
      carmen_base_odometry_message *odometry,
      carmen_handler_t handler,
      carmen_subscribe_t subscribe_how);
```

Message Example in Carmen

```
typedef struct {
  double x, y, theta;
  double tv, rv;
  double acceleration;
  double timestamp;
  char *host;
} carmen_base_odometry_message;
```

- Every message contains a timestamp and the name of the sending host

Message Example in Carmen

- Often, modules provide helper function that encapsulate sending messages
- For example, calling

```
void carmen_robot_velocity_command(
                  double tv, double rv);
```

- Sends the message

```
typedef struct {
  double tv, rv;
  double timestamp;
  char *host;
} carmen_robot_velocity_message;
```

Modules

- Most systems use the modules (or nodes)
- Often, each module represents one task (localization, path planning, a driver, …)
- Each module runs as an own process

- **Discuss:** why is this done like that?

Modules

- Most systems use the modules (or nodes)
- Often, each module represents one task (localization, path planning, a driver, …)
- Each module runs as an own process
- Modules can be replaced easily
- Modules can be distributed between machines
- If a module dies, this does not affect the other components (at least they can react)
- Separation between module and its GUI
- **Discuss:** why separating the GUI?

Separation of the User Interface

- It is a good advice to separate a component/module from is GUI
- GUIs can run remotely
- GUIs may require significant resources (on the robot, that can be critical)
- Often OpenGL GUIs for 3D visualizations will not run on the robot (graphics card)

- …but often less nice to code…

Parameters

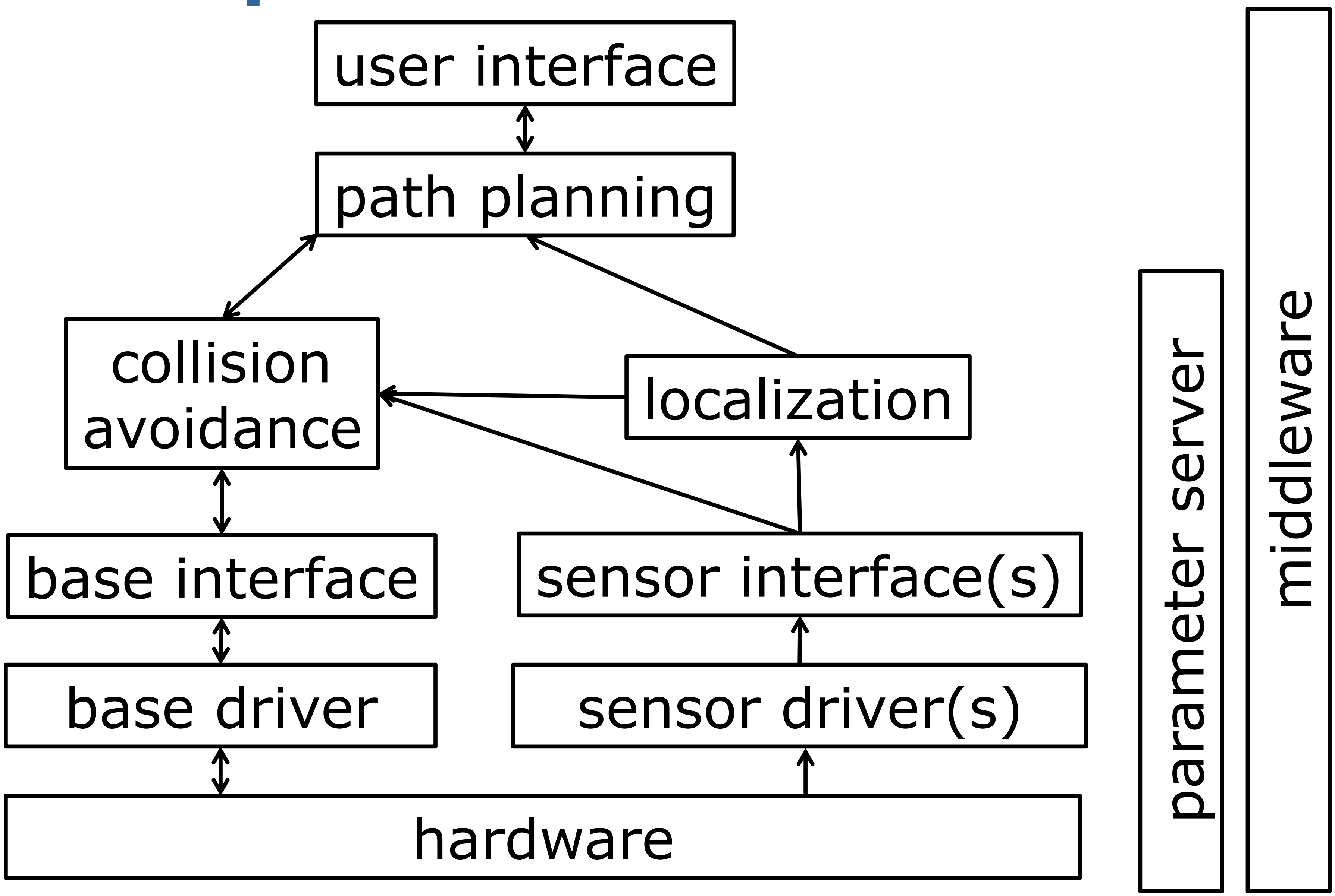
- “There should be only a single parameter file. No exceptions.”
- Parameters should be handled centrally
- Modules should only be allowed to read and write parameters via a centralized mechanism

Parameters in Carmen

- There is only on ini file
- It is read by one process (param_daemon)
- Modules can query and set parameters
- Modules get notified if a parameter has changed online
- Examples:

```
int carmen_param_get_int(char *variable, int *return_value);
int carmen_param_get_double(char *variable, double *return_value);
```

Example


user interface
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hardware
parameter server
middleware

Logging Data

- **Discuss:** why logging data?

Logging Data…

- for post-processing
- for documenting experiments
- for being independent from a robot running 24/7
- for debugging and reproducing failures
- for collecting training data
- …

Logging Data

- Good systems provide an easy way to log data
- Time-stamped data
- Transparent logging and playback (no distinction between played back data and real robot generating data online)
- Ideal case: everything can be logged transparently

Log Formats

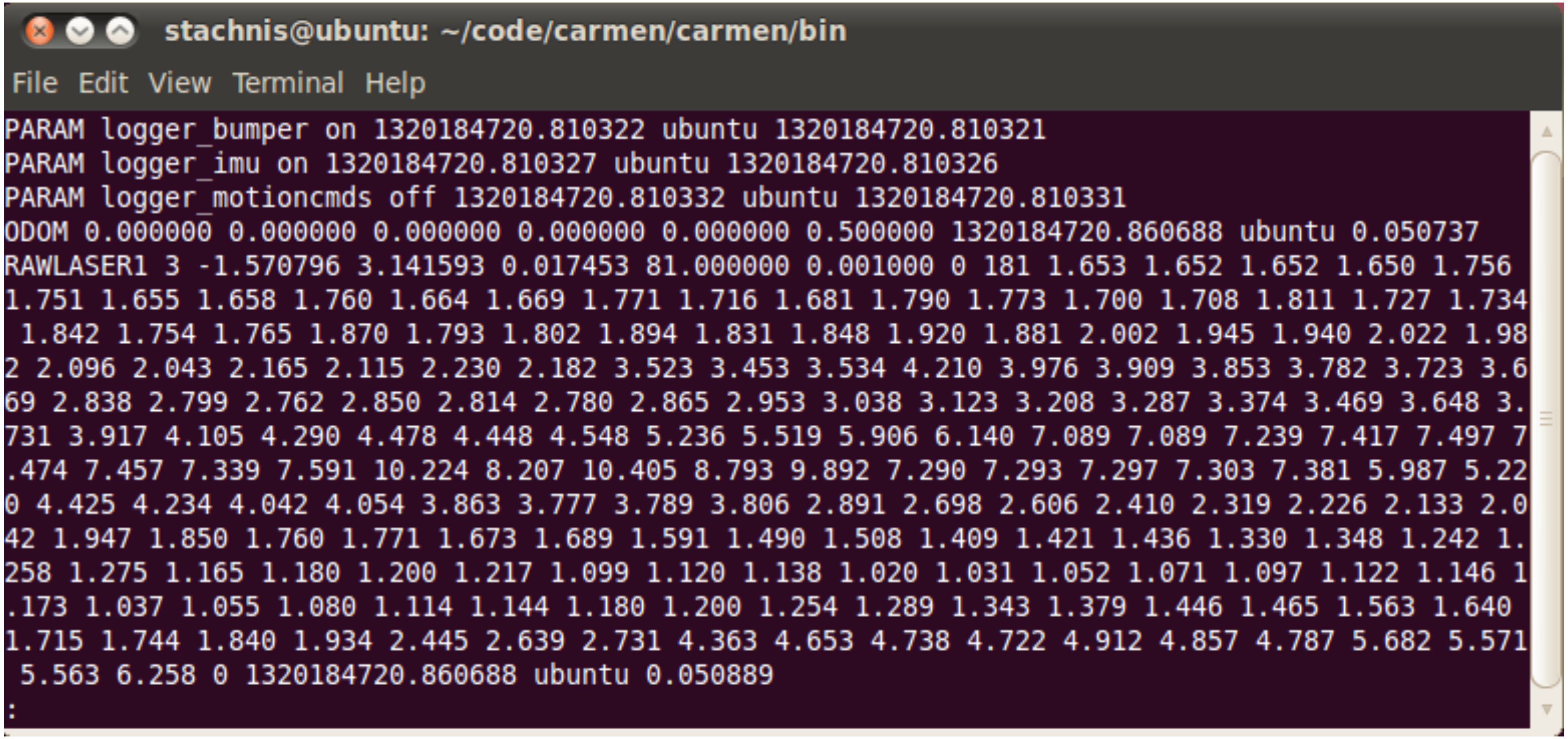
- Human readable formats vs. self-made binary formats

- **Discuss**: pros and cons!

Log Formats

- MOOS: Human readable formats, logs everything (String-based messages)
- Carmen (IPC): Human readable formats, newly defined message required changes in the logger/playback component
- ROS: binary format, can log transparently, logfile compatibility between versions

Logfile Example



Units & Coordinate Frames

- All modules should use the same units
- SI units (meter, kilogram, second, …)

- All modules should use the same coordinate frame
- … here the problems start in practice
- Different communities use different frames
- Especially in 3D, there are representations with different properties

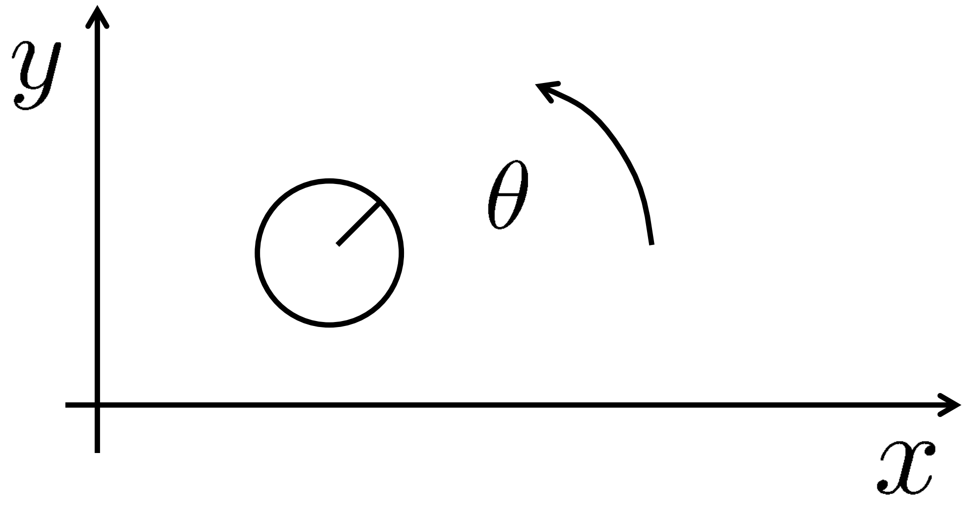
Units & Coordinate Frames

- Using different units and/or different coordinate frames is one serious sources of errors

Example: Mars Climate Orbiter, 1999

- One company used English units and the other used SI for controlling the thrusters
- This lead to a wrongly calculated orbit altitude and finally the orbiter entered the atmosphere and burned

Most Commonly Used in 2D



$\theta = 0$ looks along the x-axis

Simulations

- Simulations are always incomplete
- Simulations will never replace real world experiments

- **Discuss**: Why are simulations useful?

Simulations are Useful

- Possibility to get ground truth
- Control the amount of noise
- Control over the time dimension
- Test of the communication flow
- Test software with the risk of ruining expensive hardware
- Useful for debugging
- No hardware/robot required
- …

Summary – Important Issues

- Flexible communication architecture
- Message-based communication
- Network transparency
- Easy to use and transparent logging and playback capabilities
- Centralized parameter handling
- Abstracts higher level components from the actual hardware (robot/sensors)
- SI units and one reference frame

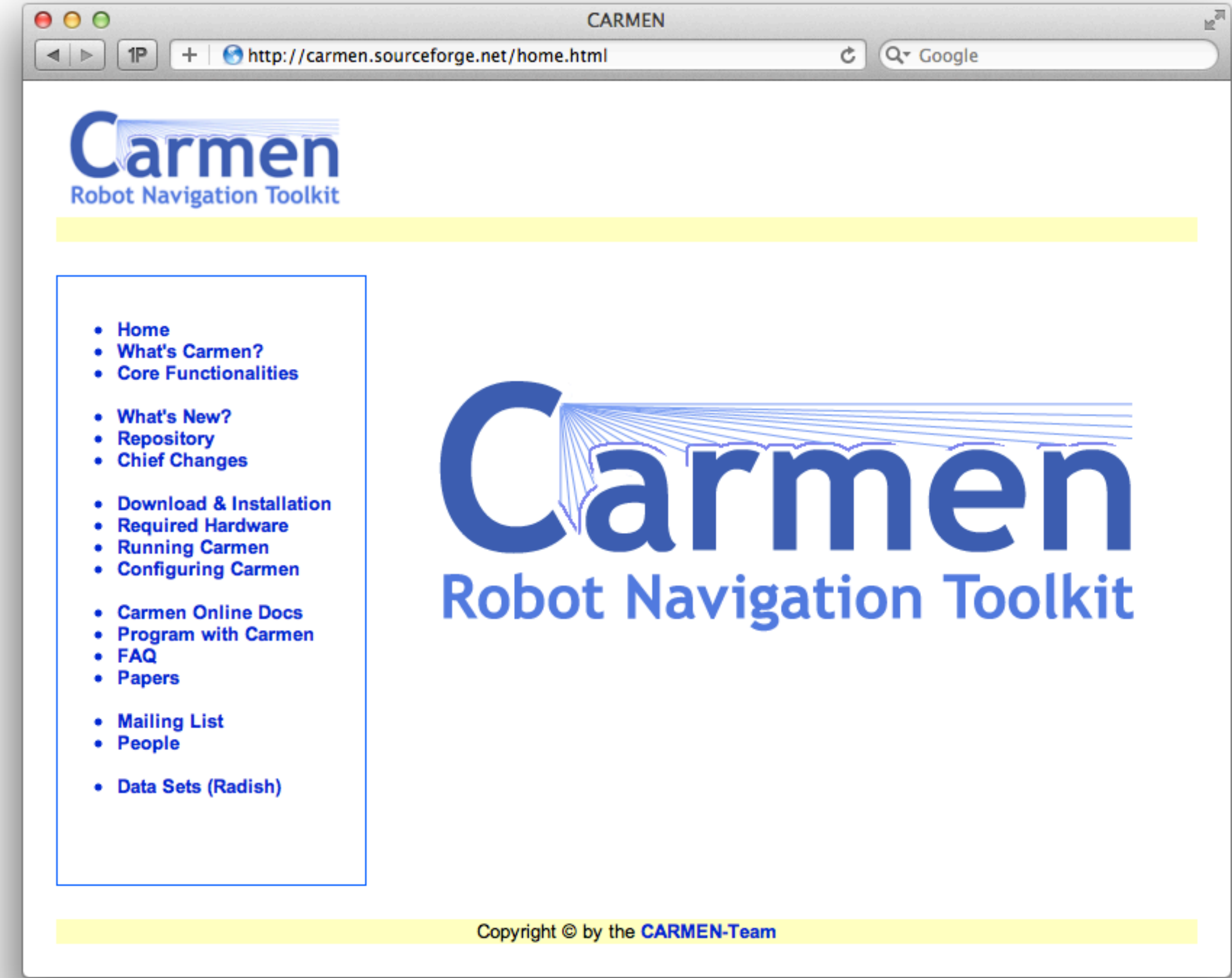
Part II: Carmen

Carmen

Robot Navigation Toolkit

…in action

More Details on Carmen



http://carmen.sourceforge.net

Install Carmen

- Download carmen from http://carmen.sourceforge.net

- tar xzf carmen.tgz ~/
- export CARMEN_HOME=~/carmen
- cd $CARMEN_HOME/src
- ./configure
- make

Running Carmen

- cd $CARMEN_HOME/bin
- ./central
- ./param_daemon –r p2d8+ ../data/freiburg.map
- ./simulator
- ./robot
- ./localize
- ./navigator
- ./navigator_panel
  (click place robot to initialize the simulator and the localization)
- ./robotgui