WHY AND HOW TO ACHIEVE DETERMINISTIC TIMING WITH ROS

WITH EXAMPLES FROM THE NAVSTACK

ROS-INDUSTRIAL CONFERENCE
3RD NOV 2016

Ingo Lütkebohle (Bosch CR/AE Software Platforms and Technologies)

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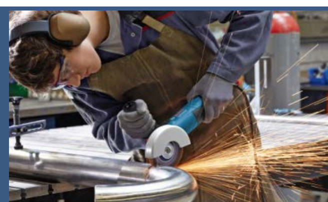

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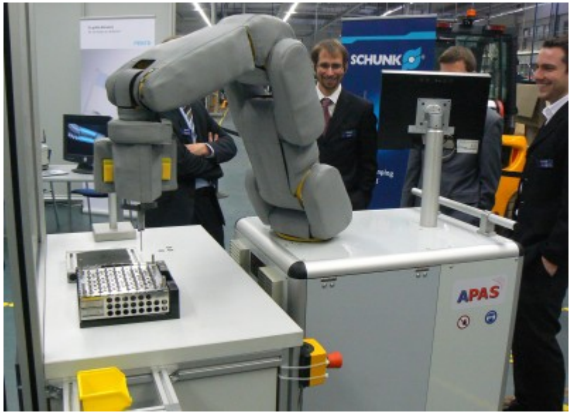
(Some of) our Robots



(How)
Can we use
ROS for that?

Recap
Bosch CR’s view on ROS

- ROS1 strengths…
  - …excellent for getting started quickly
  - …has a lot of components available
  - …great for working with academia
  - …offers best-in-class tool support (recording, visualization)
- ROS1 weaknesses
  - …composition and checking is lot of manual effort
  - …component quality varies widely
    - many components don’t work outside of very narrow use-cases
  - …real-time support is very limited
  - …predictability of system behavior is extremely limited

Limited scalability

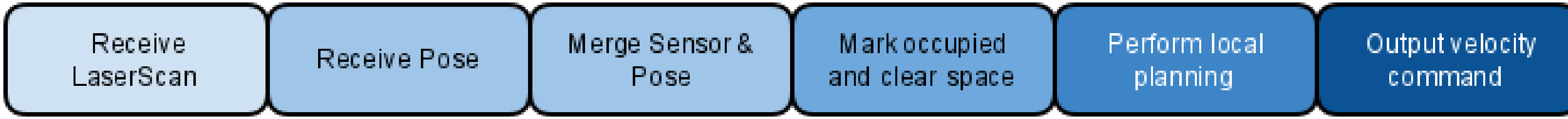
No safety support

That’s what we are working on ☺

Agenda

1. Motivation: Predictable execution in an asynchronous system
2. Timing Analysis as a tool to measure and achieve deterministic execution
3. Example: Improvements to ROS move_base
4. Outlook and Discussion

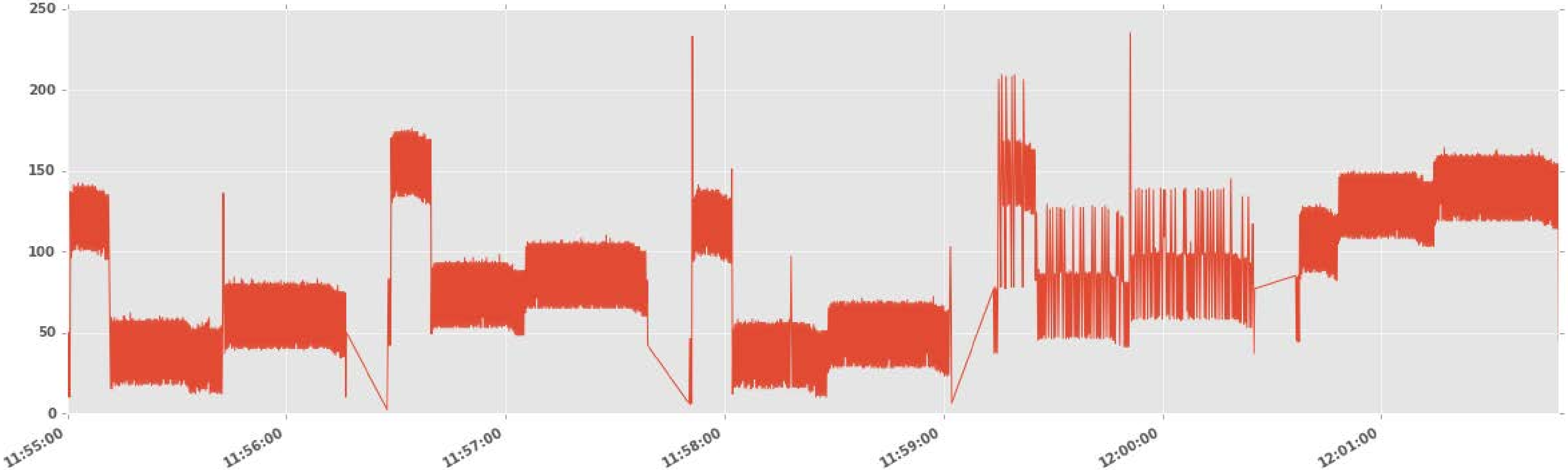
Why we need timing analysis
Basic obstacle avoidance pipeline



- In other words: Get sensor data, do some processing, act
- Real-world issue
  - **How long from obstacle sensing to drive stop?**
  - And, can we be sure this is always the case?
- Timing view
  - What's the *response time*?
  - Is the behavior (and hence response time) *deterministic*? ("does it always do the same steps in the same order?")

Why we need timing analysis
Response time experiment

- Three nodes: Laser, move_base, base driver
- No direct info on end-to-end timing available
- Initial analysis: move_base planning stage is good indicator
- Questions
  - How long does the move_base take to plan?
  - How old is the sensor data used for planning?
    (aka, when was the costmap last updated)



Why we need timing analysis
Summary of current situation

- Controller runs at configured rate (e.g., 10Hz)
  - But it often **uses old data**
- Data age has behavioral effect
  - Little change when map is known and static – assuming odometry is current
  - But delayed reaction to dynamic obstacles **can lead to collisions**
  - Semi-static obstacles in occluded regions can also be affected
- Varying behavior is problematic for testing
  - Sometimes it works, sometimes it doesn't...

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Objectives
We want to find out *why* this happens

- Could be due to…
  - Differences in computation time from one run to the next
  - Differences in system load during execution
  - Different movement speeds
  - Some change in the environment
  - Data fusion/windowing
  - Sampling between runnables with different rates
- ROS has great tools, but they only look at the interface, not inside

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Our Approach
Instrument, analyze, refactor

- Measure
  - Framework timing instrumentation – available out-of-the-box
  - Support for custom instrumentation – user-defined, integrated with above
- Analyze
  - Measurement-based response time analysis
    - Integrated analysis of generic and custom tracepoints
- Refactor
  - Information to guide architectural changes

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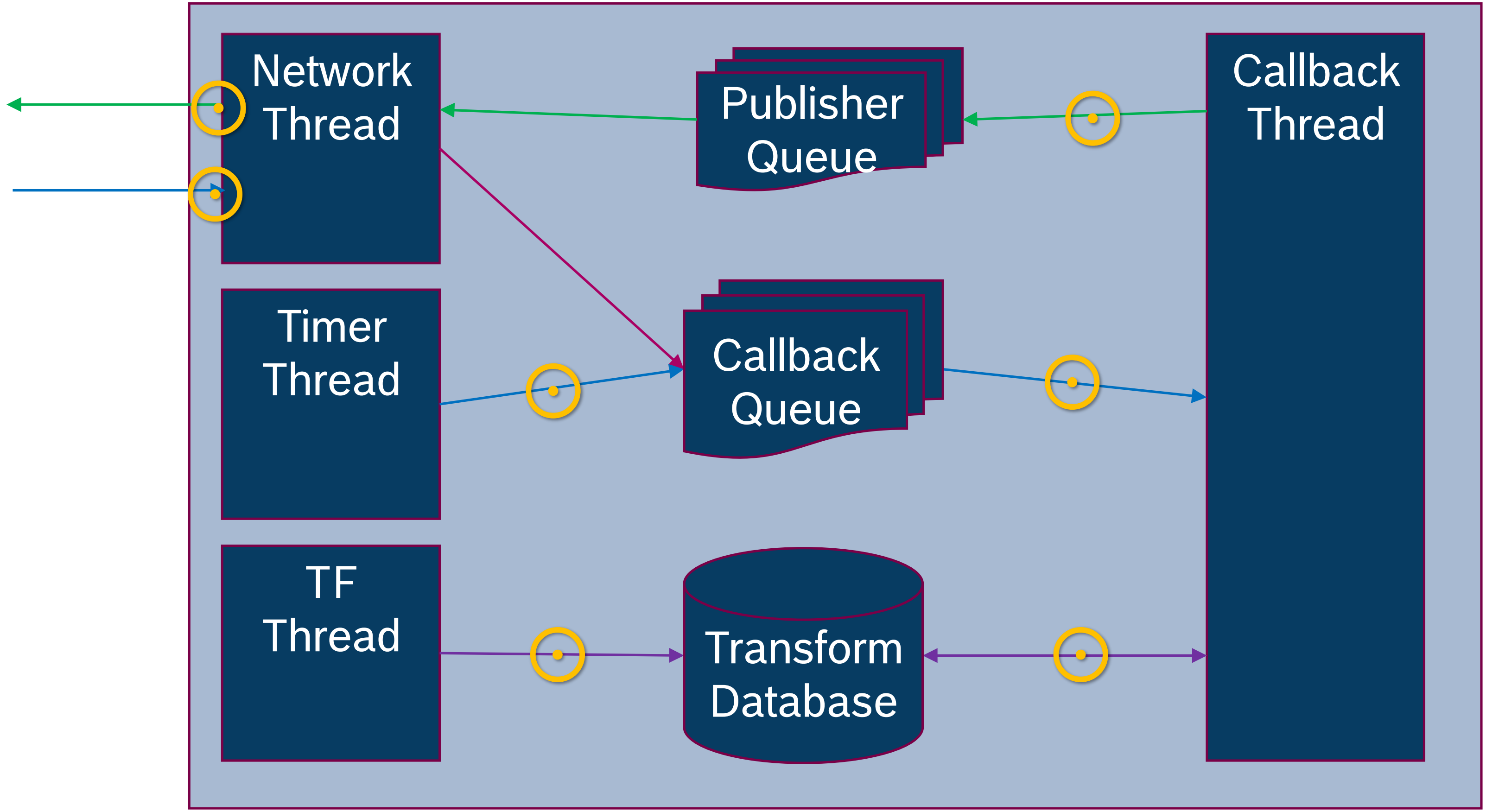
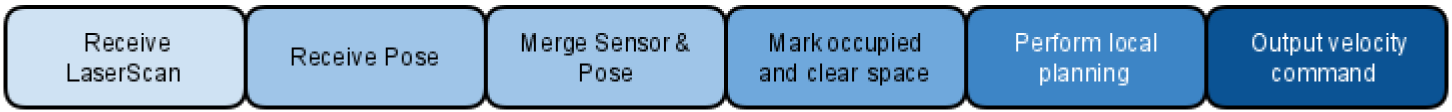
Our Approach
Generic tracepoints in roscpp

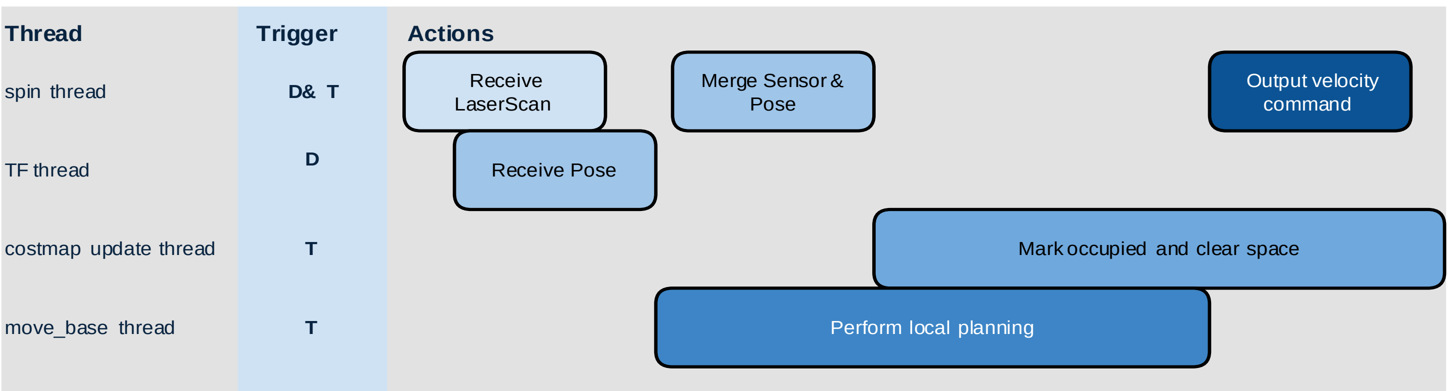


Case Study
move_base's internal pipeline

- Recap: Basic processing stage



- Move_base realization: 4 threads, not synchronized



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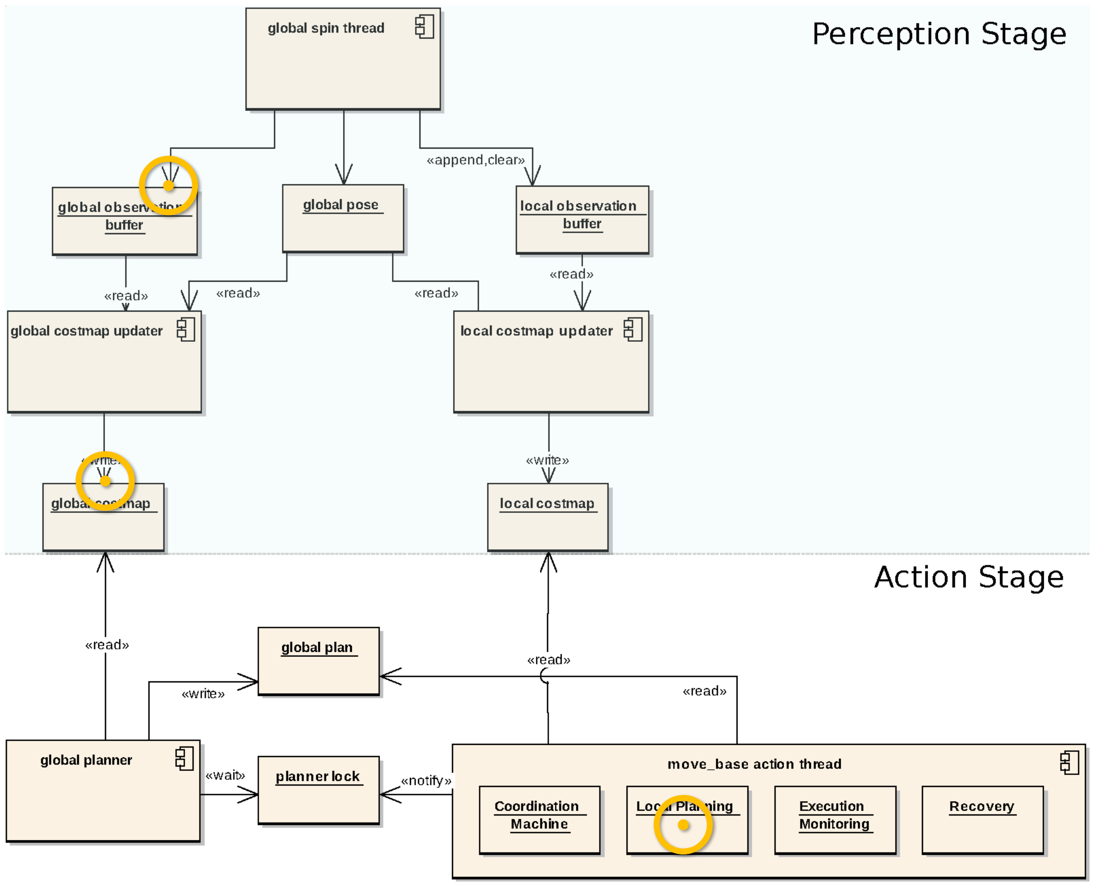
Case Study
Observations

- Perception and planning are not synchronized
- They run at different rates
  - Laser at 12.5Hz (SICK LMS300)
  - Costmap update at 5Hz
    - And further delayed by TF, until pose for sensor timestamp is available
  - Planner at 10Hz

Our Approach
Custom Tracepoints in move_base



Case Study
Procedure

- Run move_base in various configurations with tracing enabled
  1. Standard configuration (as shown before)
  2. Configuration where processing runs at sensor-rate
  3. Refactor as necessary
- Compare response times

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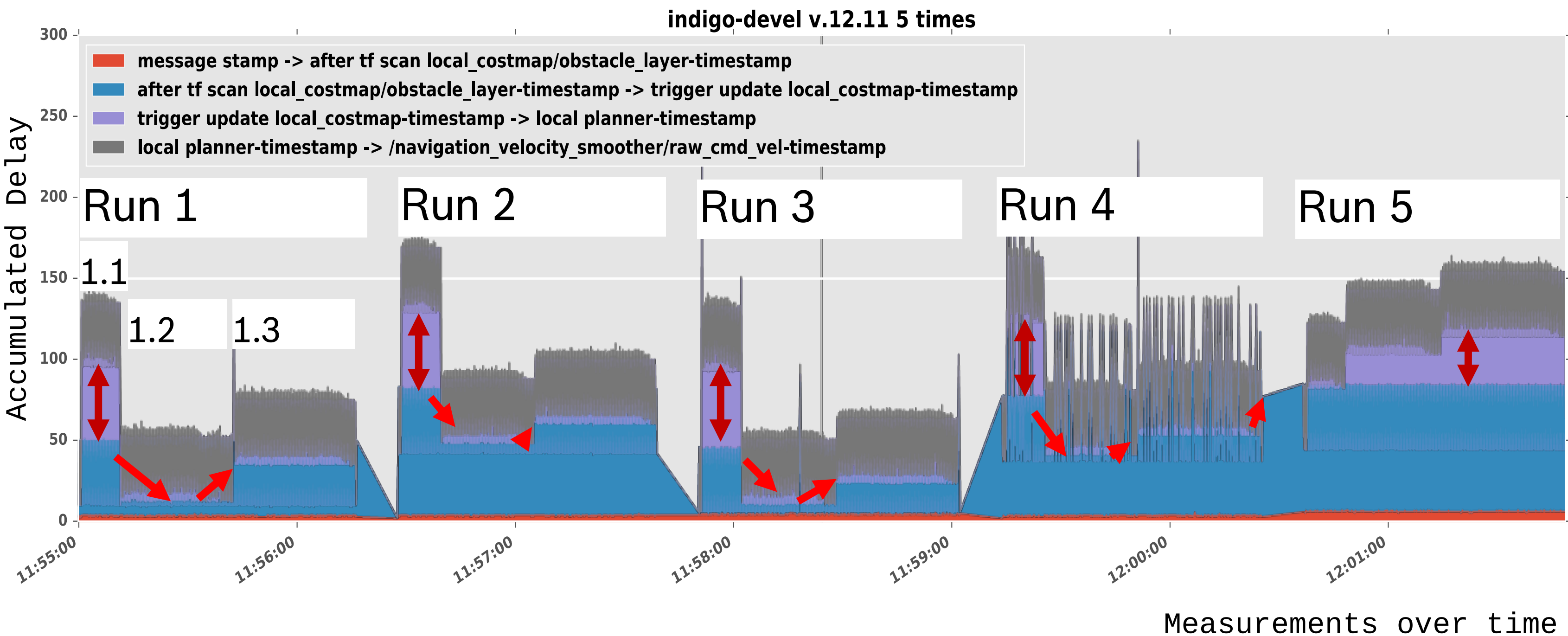
Case Study Results
Part 1: Default behavior



Not just delays, but also unpredictable change in execution order

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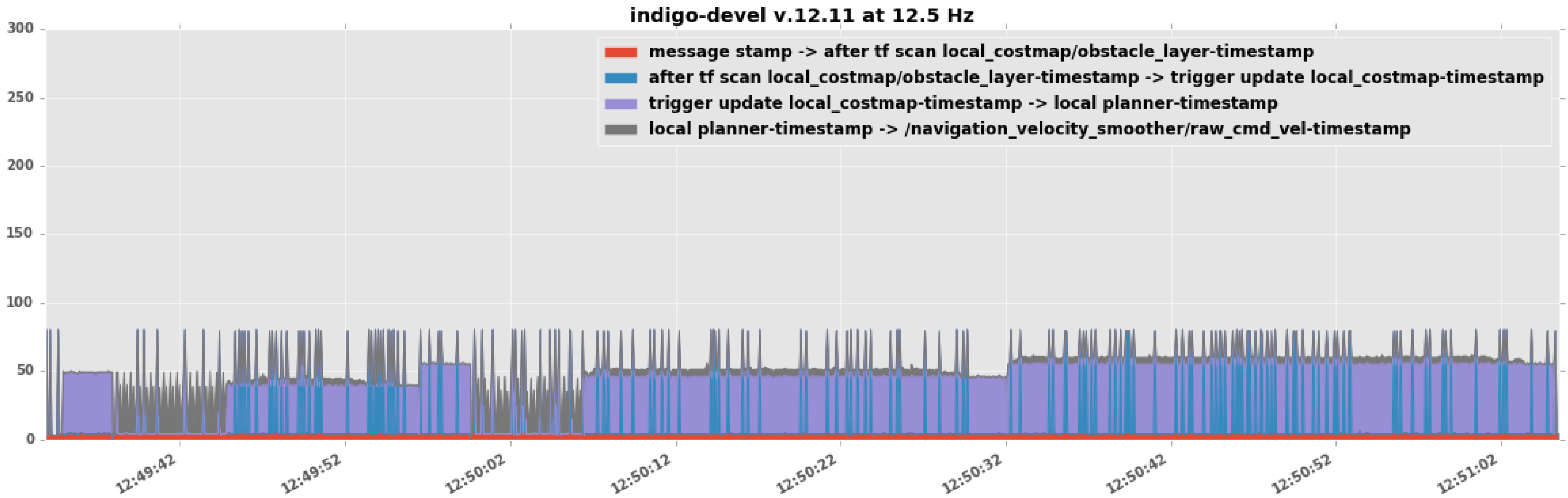
Case Study results

Part 2: Run everything at sensor rate



- Observation: Overall lower response time, but **very jittery**
- Cause: Slight differences in activation cause **execution re-ordering**

Case Study Extension
Analysis and Refactoring

- We see significant processing jitter
  - This is typical for asynchronous processing
- Refactoring to make move_base processing synchronous
  - Map update step and planning executed sequentially
  - Planning (incl. update) invoked triggered by sensor data reception

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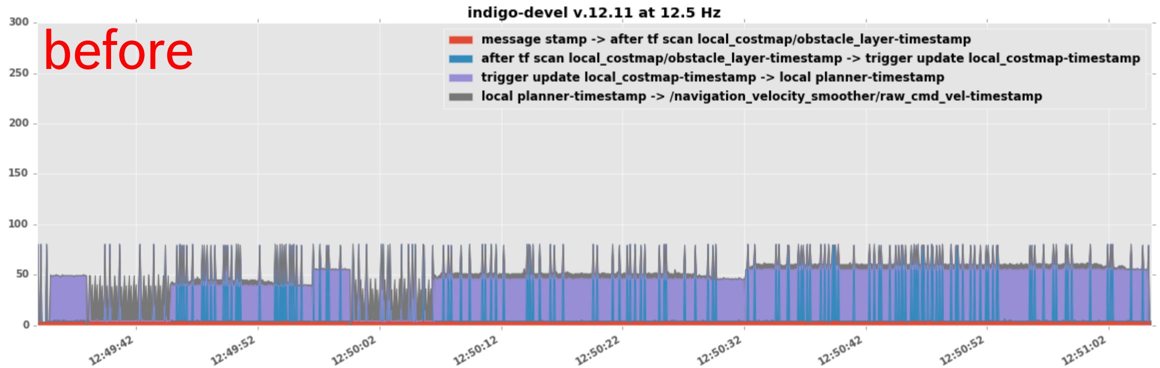
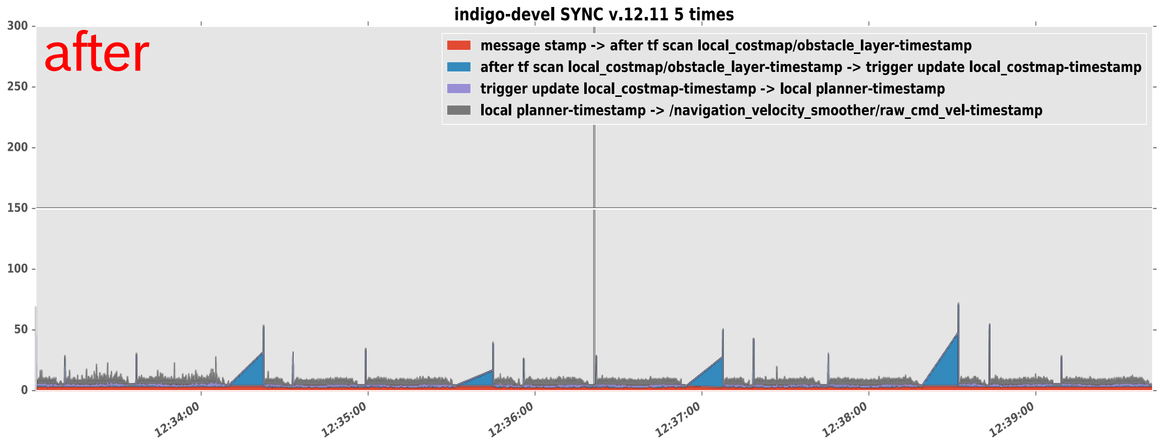
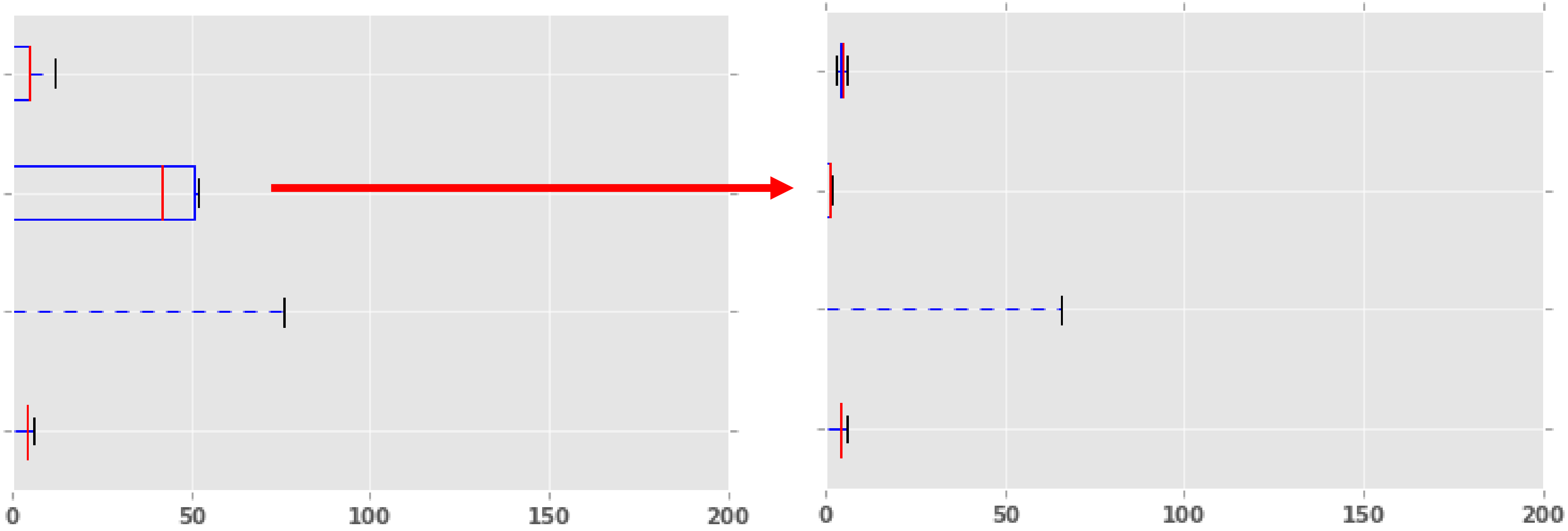
Case Study Results
Refactored timings, comparison





Case Study Results
Timing Boxplots



- Drastically reduced mean response time (mean 85ms → mean 9ms)
- Huge jitter reduction (60ms → 5ms std)
- **Bounded** max delay

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Deterministic Timing for ROS
Summary

- Deterministic behavior is not automatic for component-based systems
  - Particularly asynchronous, periodic execution is problematic
- Measurement tools need to look *inside* the framework and the app
- We have found issues with move_base that have been there for years
  - Performed refactoring with minimal changes
    - Still time-triggered, but activation synchronized
    - Response time reduced almost to pure computation time
- Conclusions
  - Principled measurement and reasoning about execution ordering is essential for robustness (and performance!)
  - Timing analysis can provide this
  - Let’s talk about better built-in support!

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