

F1/10

# Autonomous Racing

Introduction  
To ROS

Madhur Behl

Acknowledgements

AutoWare  
Open Robotics ROSCON

# Announcements

- VM and ROS installation instructions posted on Webpage/Piazza.
- Install VM on your laptop.
  - Install Ubuntu on VM or dual boot your laptop with an Ubuntu install.
  - **Tutorial0-a**
  - **16.04** or 18.04
- Install ROS on Ubuntu and bring it for the lab session on Tuesday.
  - **Tutorial0-b**
  - **ROS Kinetic Kame** or Melodic



*“Does your car have any idea why my car pulled it over?”*

Create a free ROS Development Studio Beginner account for backup

The screenshot shows the homepage of theROS Development Studio website. At the top, there's a navigation bar with icons for social media, a search bar containing 'theconstructsim.com/rds-ros-development-studio/', and links for LOGIN, BLOG, English, and SUPPORT. Below the navigation is a dark header with the 'The Construct' logo and 'For ROS Developers'. The main content area features a large white 'ROS Development Studio' title over a blurred background image of a workspace with a computer monitor, keyboard, and desk lamp. A subtitle below the title reads 'Develop your ROS project from a single place online'. At the bottom, there are two buttons: a red 'Get started >' button and a white 'Log In' button.

theconstructsim.com/rds-ros-development-studio/

LOGIN BLOG English SUPPORT

The Construct  
For ROS Developers

HOME ROS Development Studio

ROS Development Studio

Develop your ROS project from a single place online

Get started > Log In

# Today's lecture

- A gentle introduction to ROS.

# Localization and Mapping

Where am I ?

# Scene Understanding

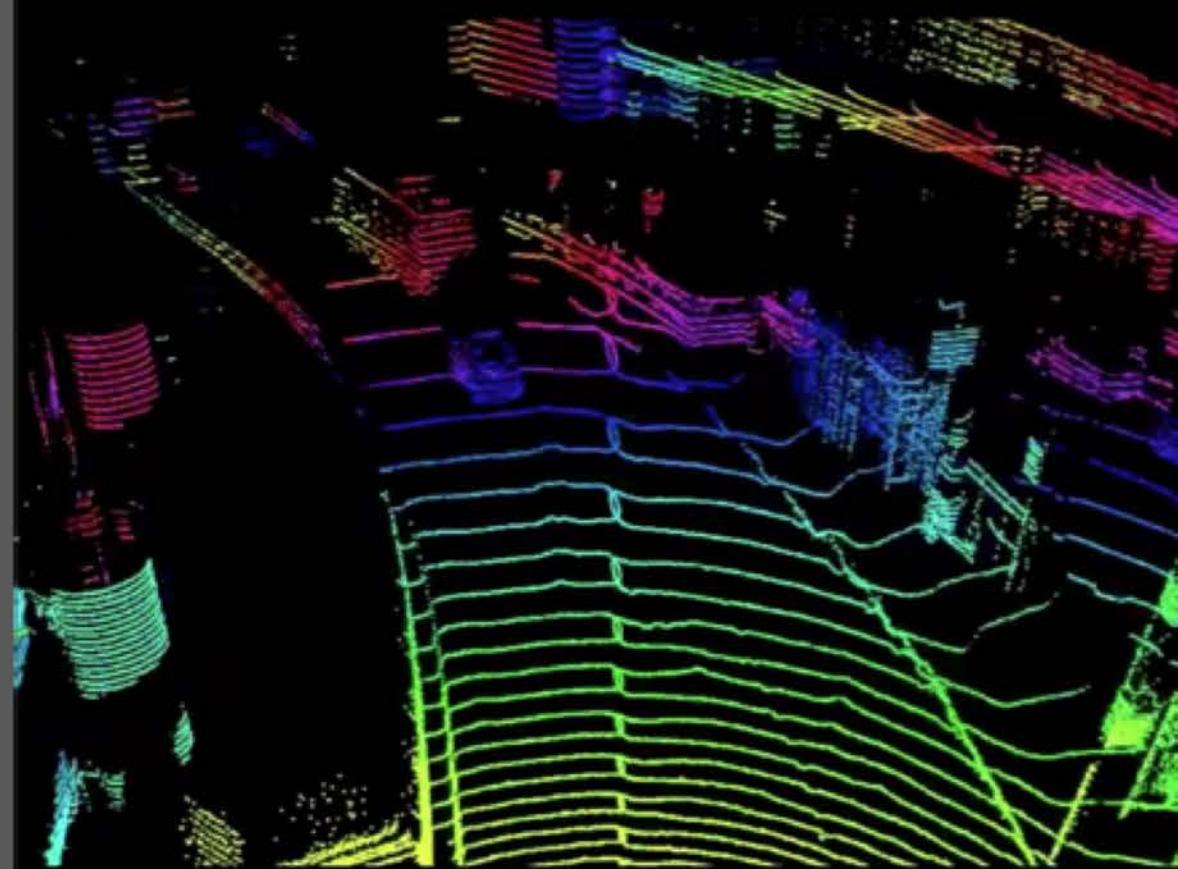
Where/who/what/why of everyone/everything else ?

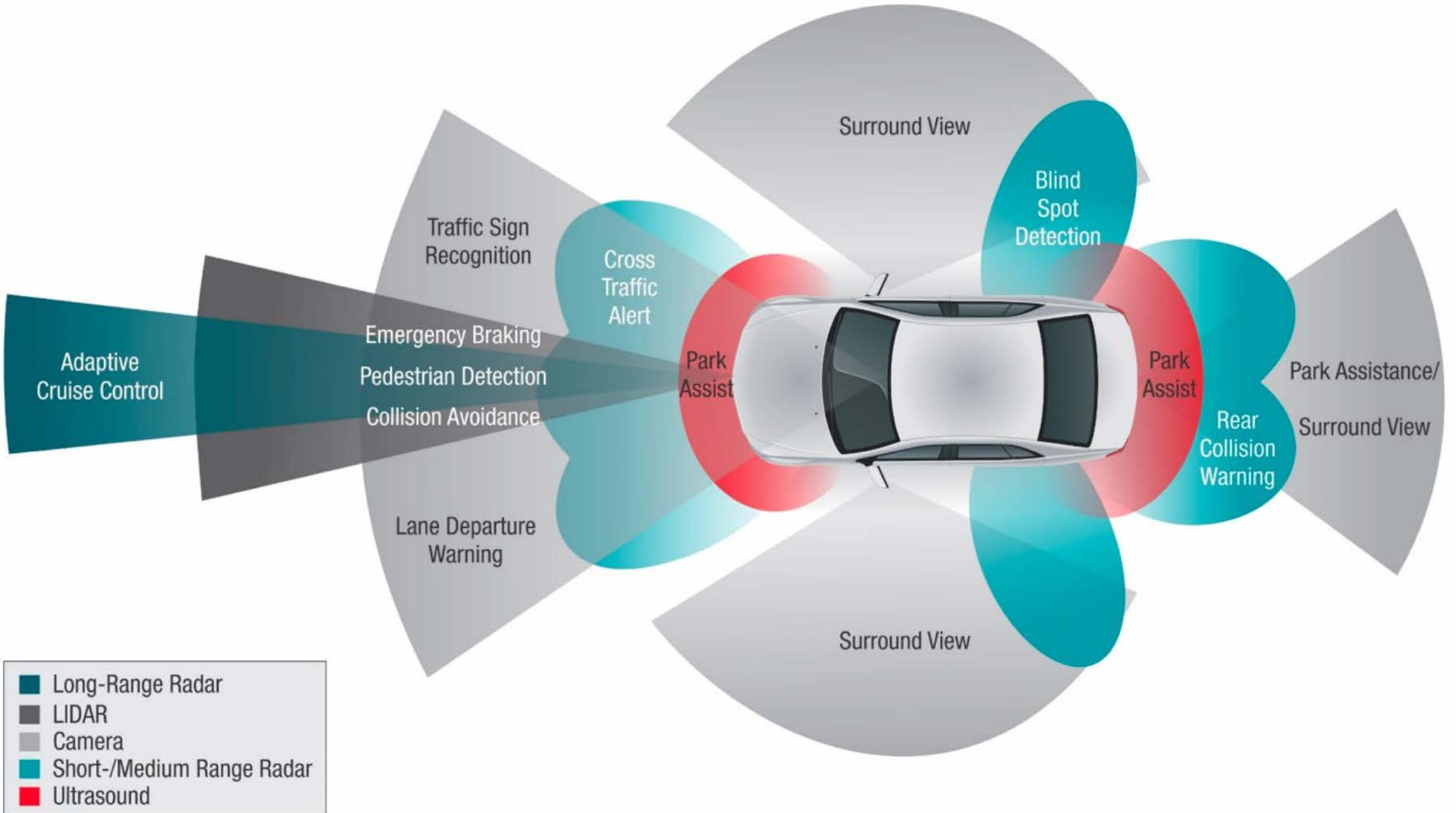
# Trajectory Planning and Control

Where should I go next ?  
How do I steer and accelerate ?

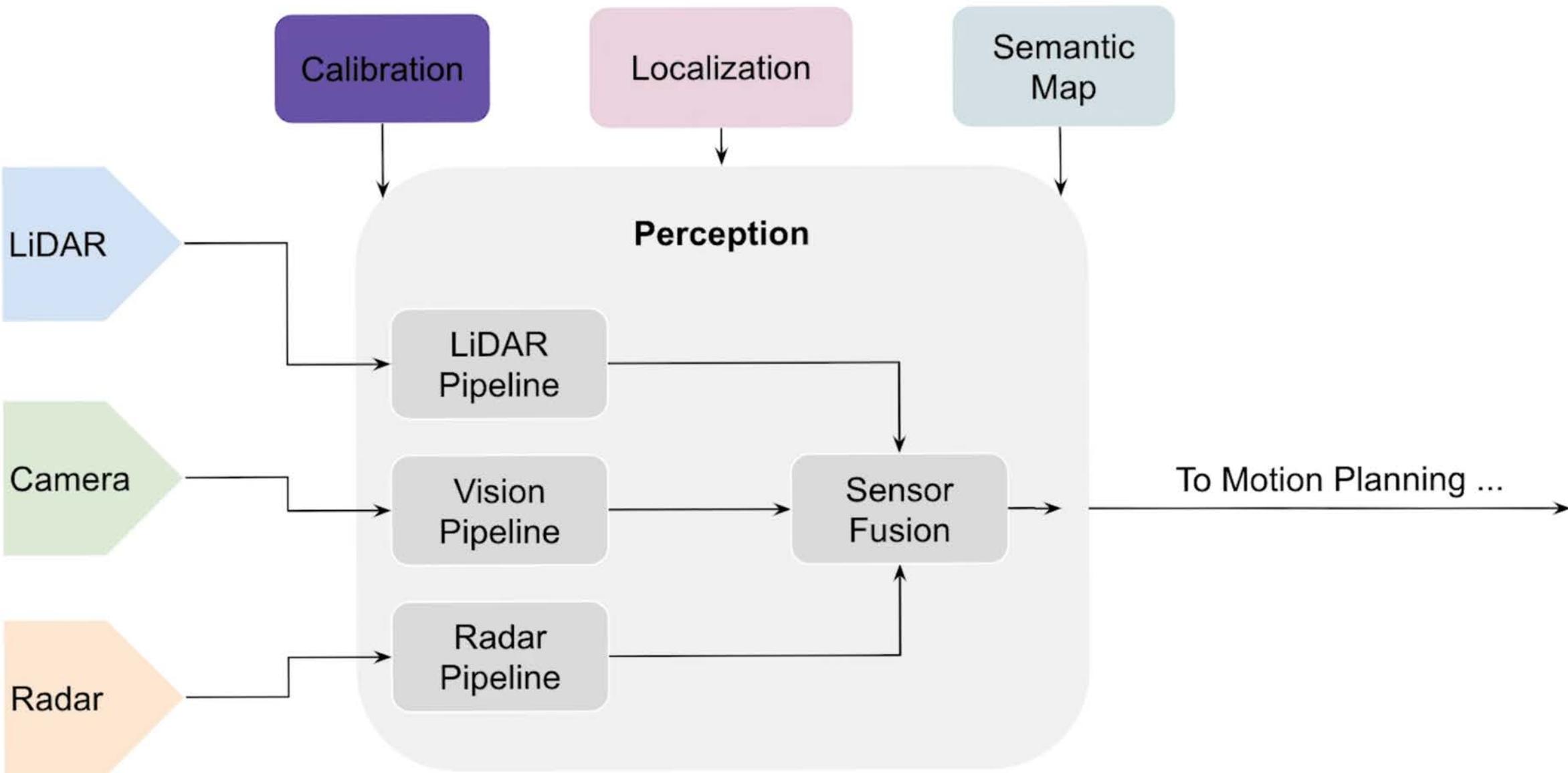
# Human Interaction

How do I convey my intent to the passenger and everyone else ?



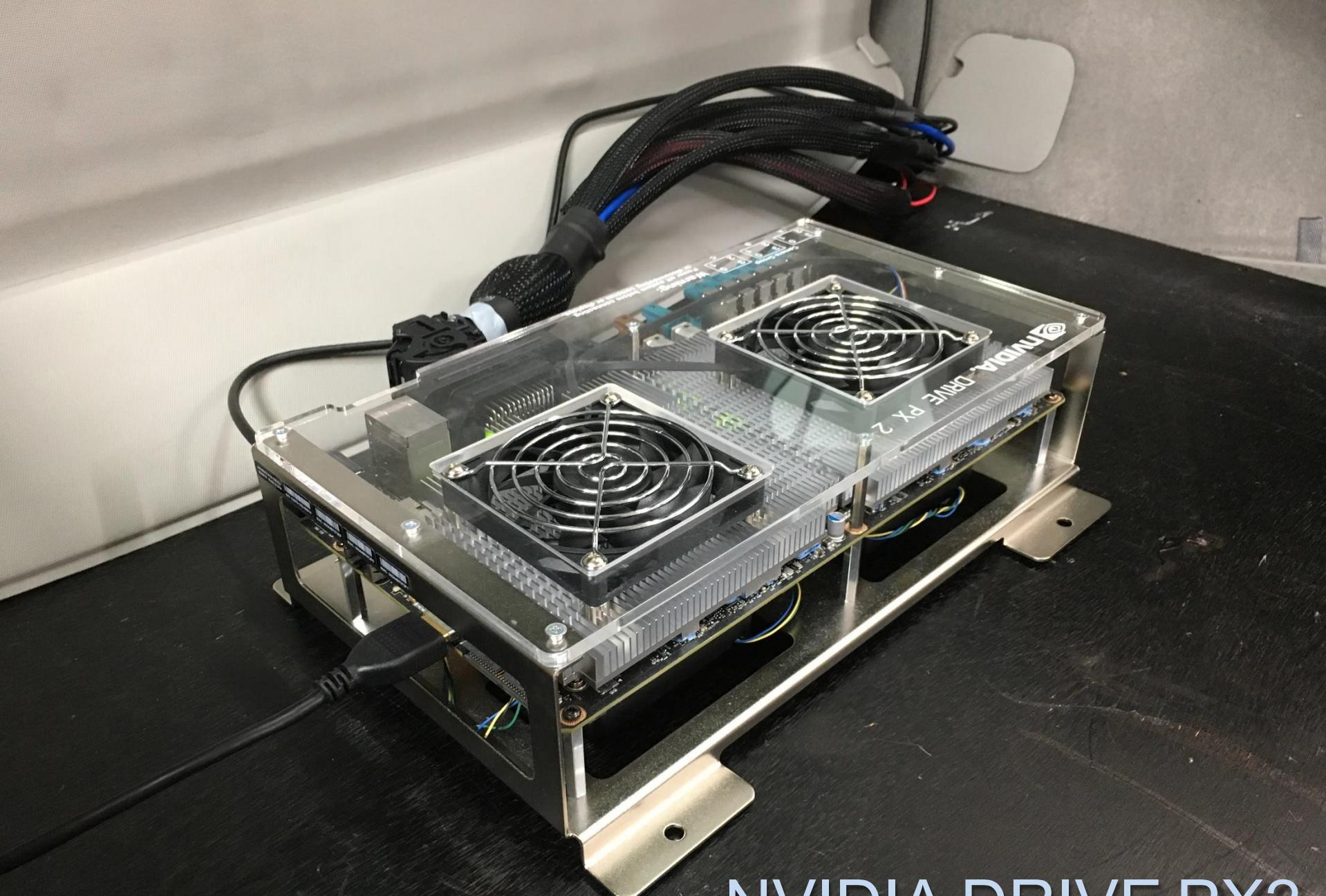


# Perception in AV Stack





**IBEO LUX 8L (3D LiDAR)**



NVIDIA DRIVE PX2



# Sensor Integration



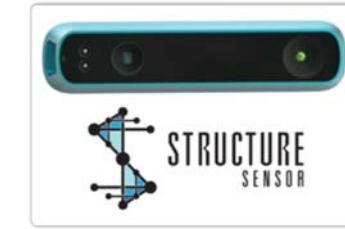
**LiDAR**



**Camera**



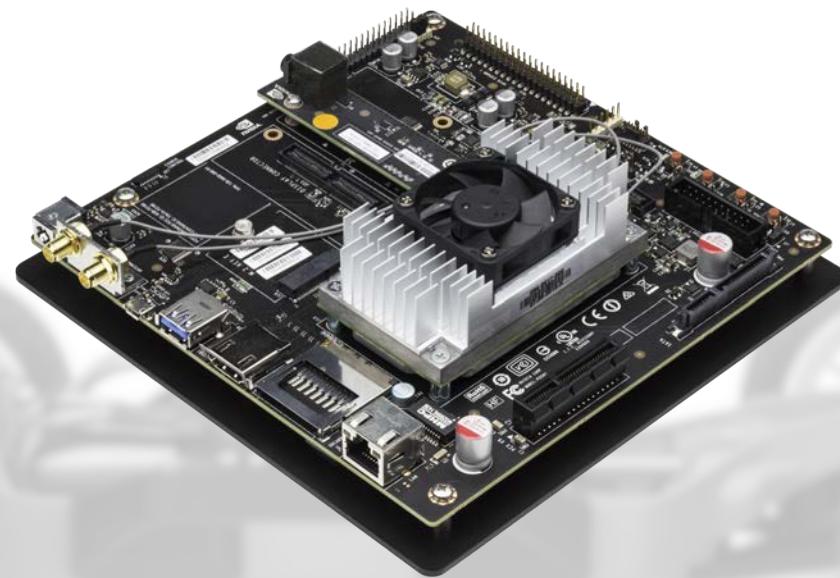
**IMU**



**IR Depth Cameras**



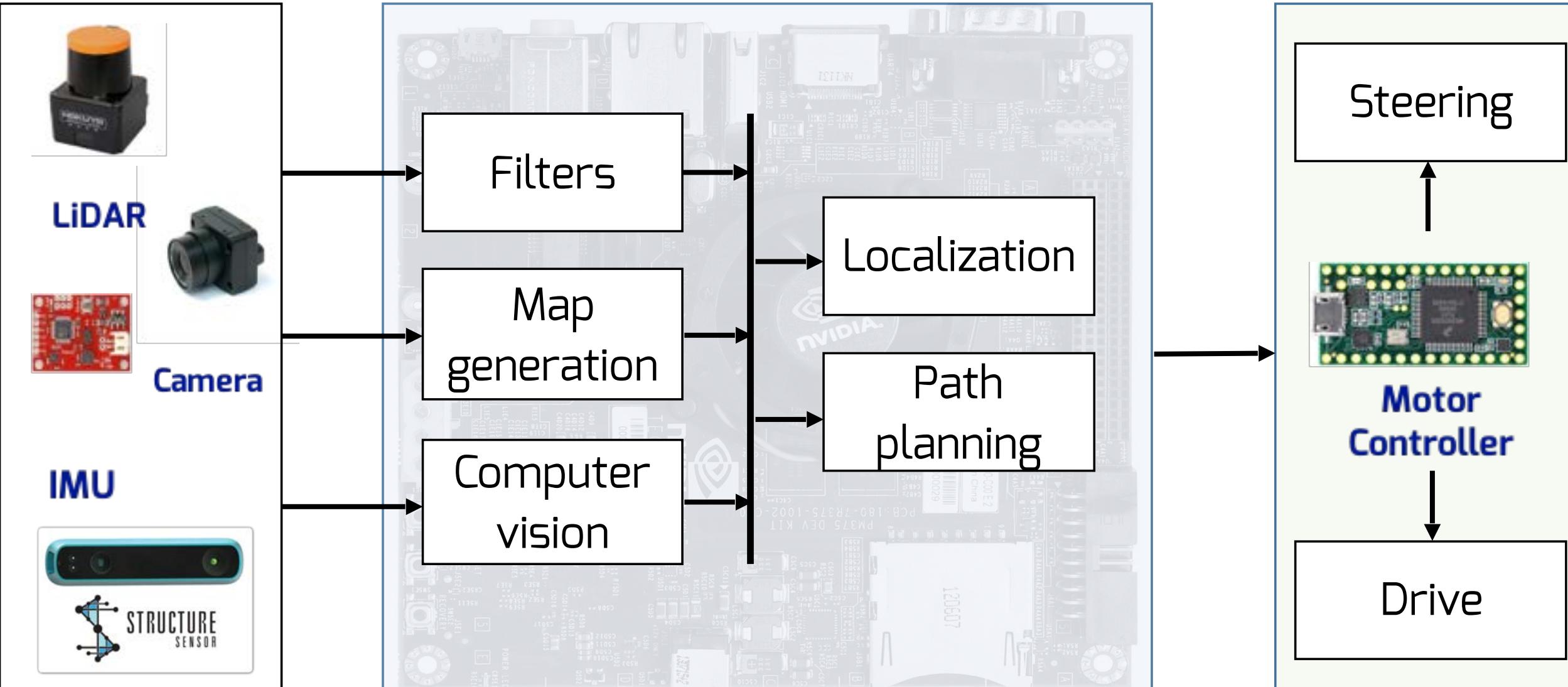
**Wi-fi Telemetry**



**Onboard Computer**



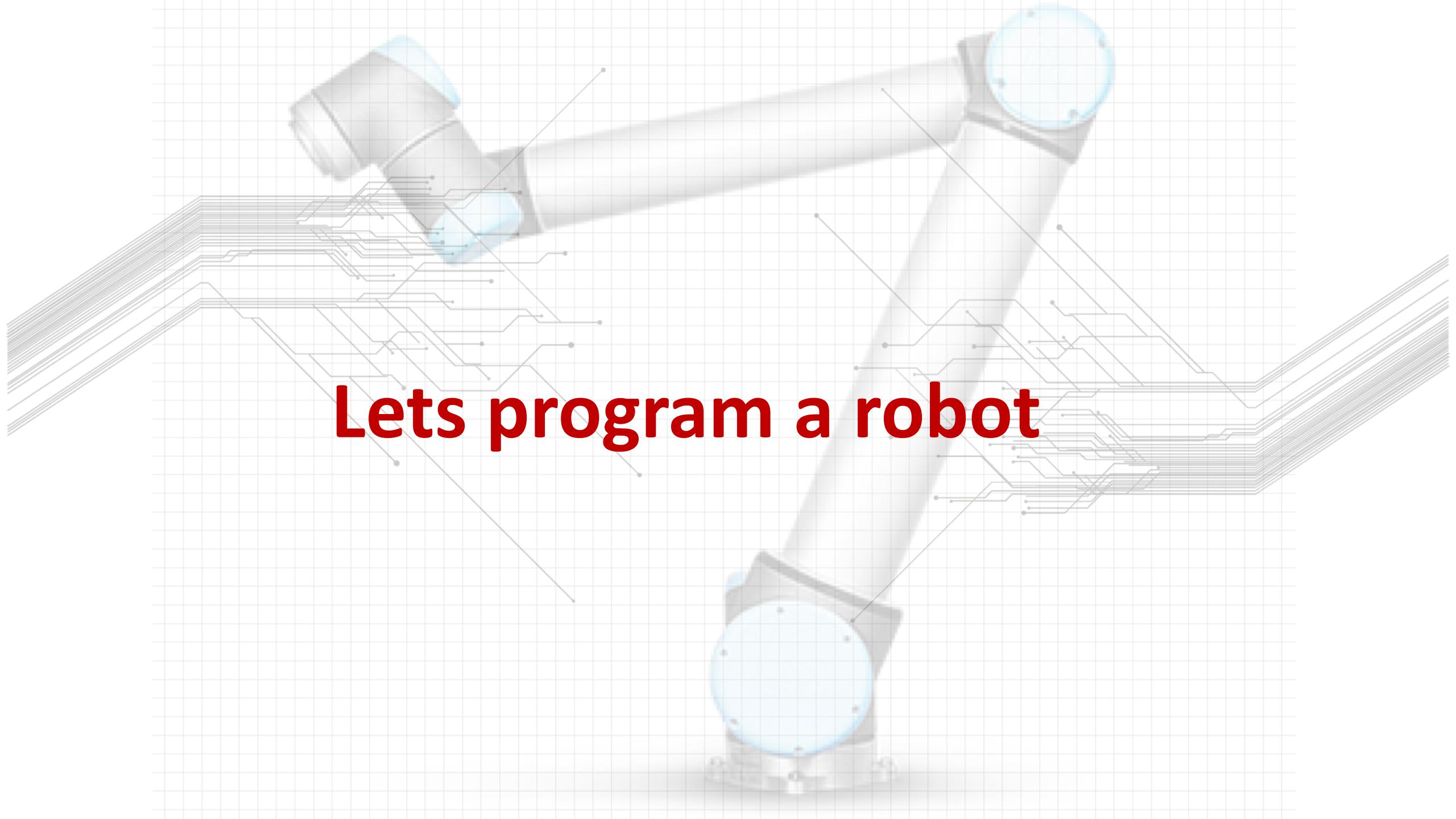
**Motor Controller**



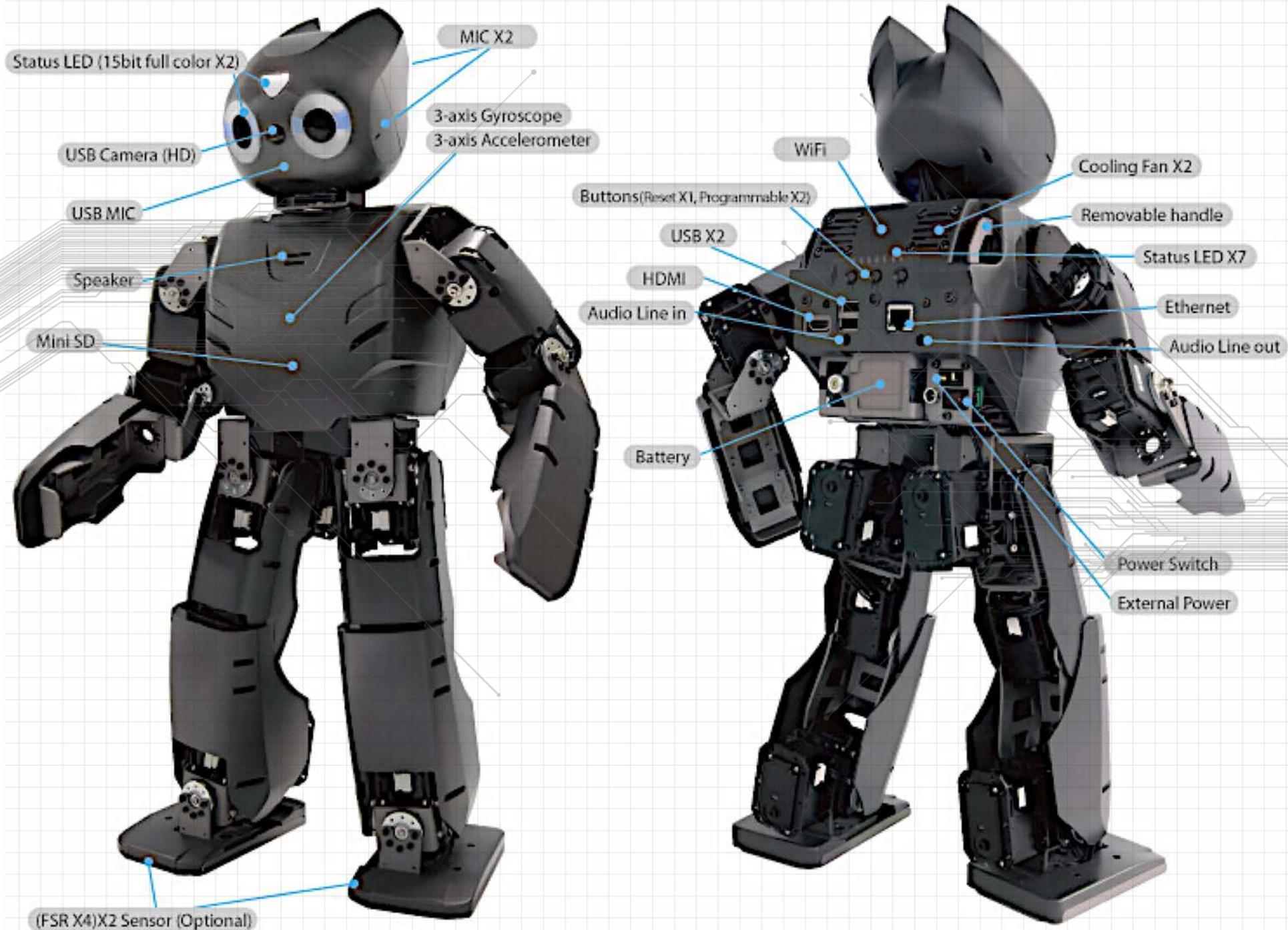
Perception

Planning

Control

A robotic arm with a magnifying glass is shown examining a printed circuit board (PCB). The PCB has several layers of tracks and components. The robotic arm is positioned over the board, with its gripper holding a magnifying glass to inspect a specific area. The background is a light gray.

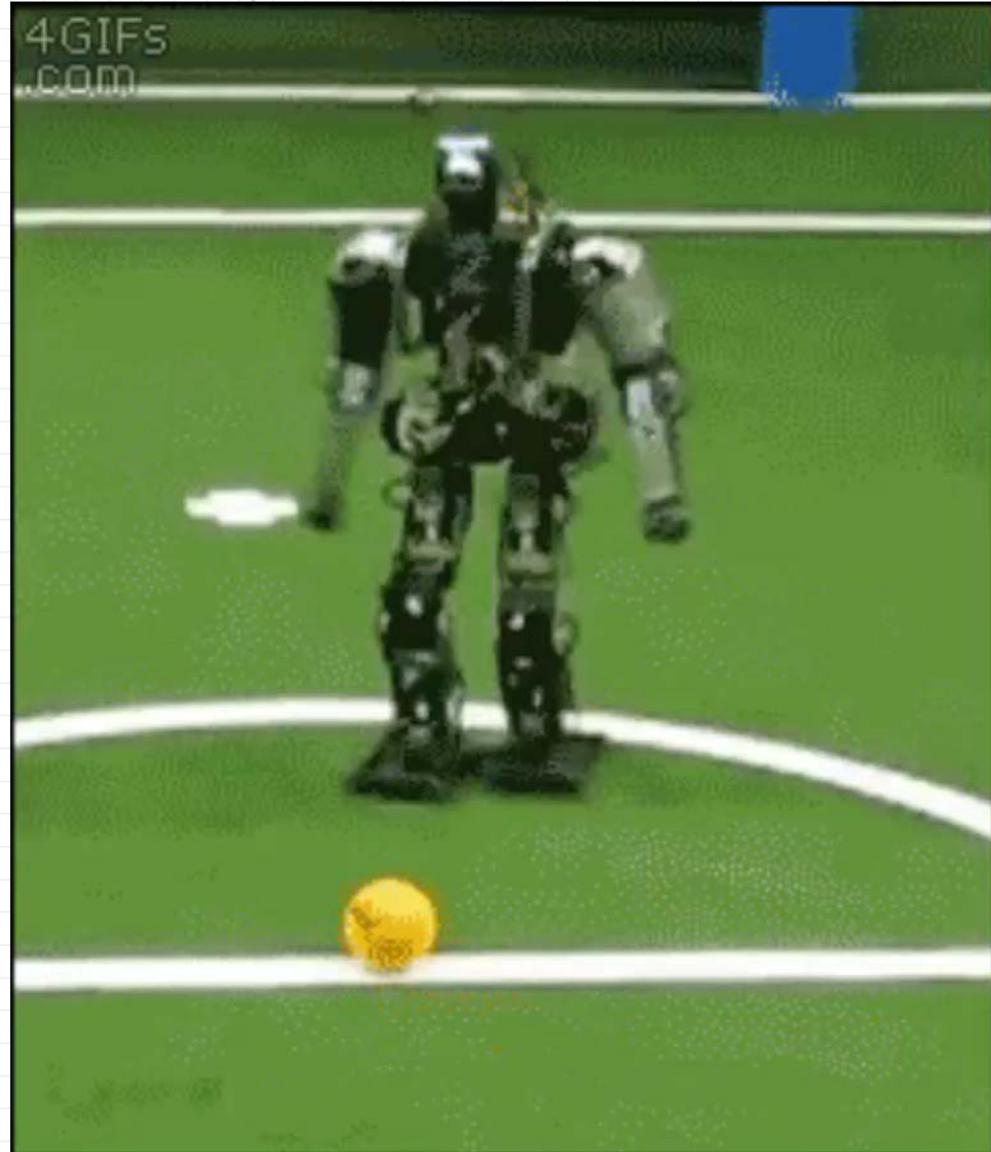
**Lets program a robot**





## Monolithic, Sequential

```
↓  
read_from_rgbd_camera(...)  
detect_soccer_ball(...)  
update_ball_tracker(...)  
convert_rgbd_to_laser(...)  
    read_odometry(...)  
update_localization(...)  
update_motion_plan(...)  
send_motion_commands(...)
```



# Challenges of Robotics Software Development\*

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- **Complexity**
  - Interconnected algorithms
  - Significant internal state
  - Concurrency
  - Multi-rate and asynchronicity
  - Multi-agent / distributed
- **Large-scale**
  - Distributed expertise
- **Resilience**
  - Fault isolation
- **Flexibility**
  - Changing configurations
  - Rapid prototyping
- **Difficult algorithms**
  - Real-time
  - Computation, bandwidth, & memory
- **Re-use**
  - Integration into other systems
  - Portability to other robot platforms



**What a mess!**

How can we deal with it ?

# ROS: Robot Operating System



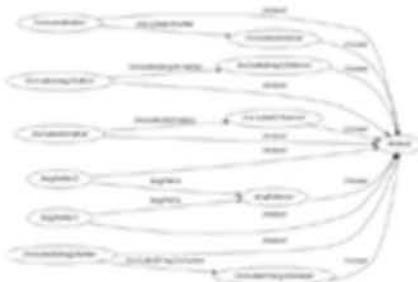
About    Why ROS?    Getting Started    Get Involved    Blog

## What is ROS?

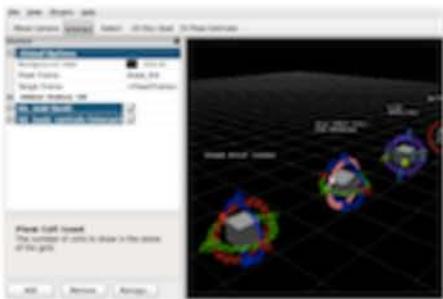
The Robot Operating System (ROS) is a set of software libraries and tools that help you build robot applications. From drivers to state-of-the-art algorithms, and with powerful developer tools, ROS has what you need for your next robotics project. And it's all open source.

[Read More](#)





+



+



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ros.org

## Plumbing

- Process management
- Inter-process communication
- Device drivers

## Tools

- Simulation
- Visualization
- Graphical user interface
- Data logging

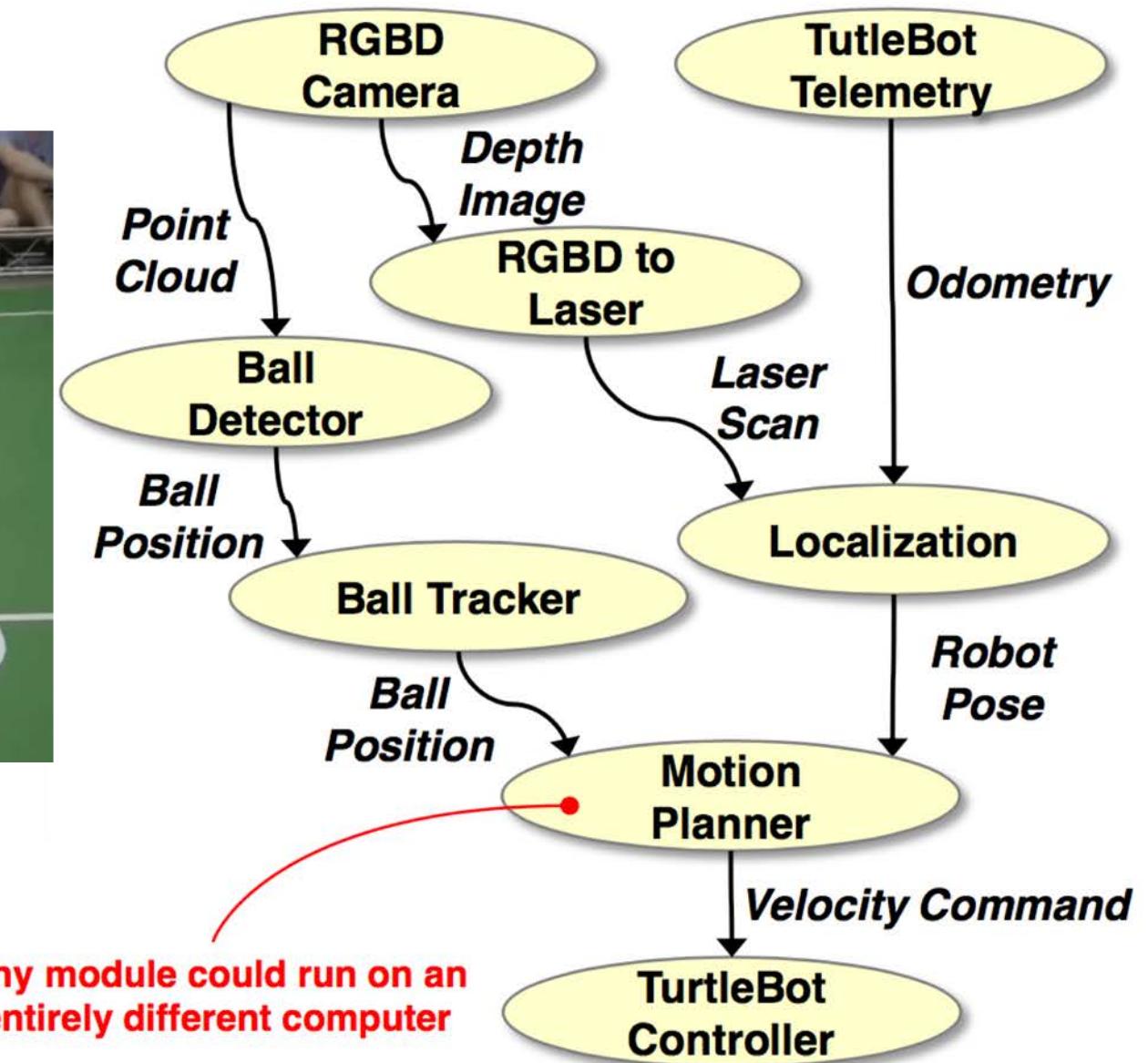
## Capabilities

- Control
- Planning
- Perception
- Mapping
- Manipulation

## Ecosystem

- Package organization
- Software distribution
- Documentation
- Tutorials

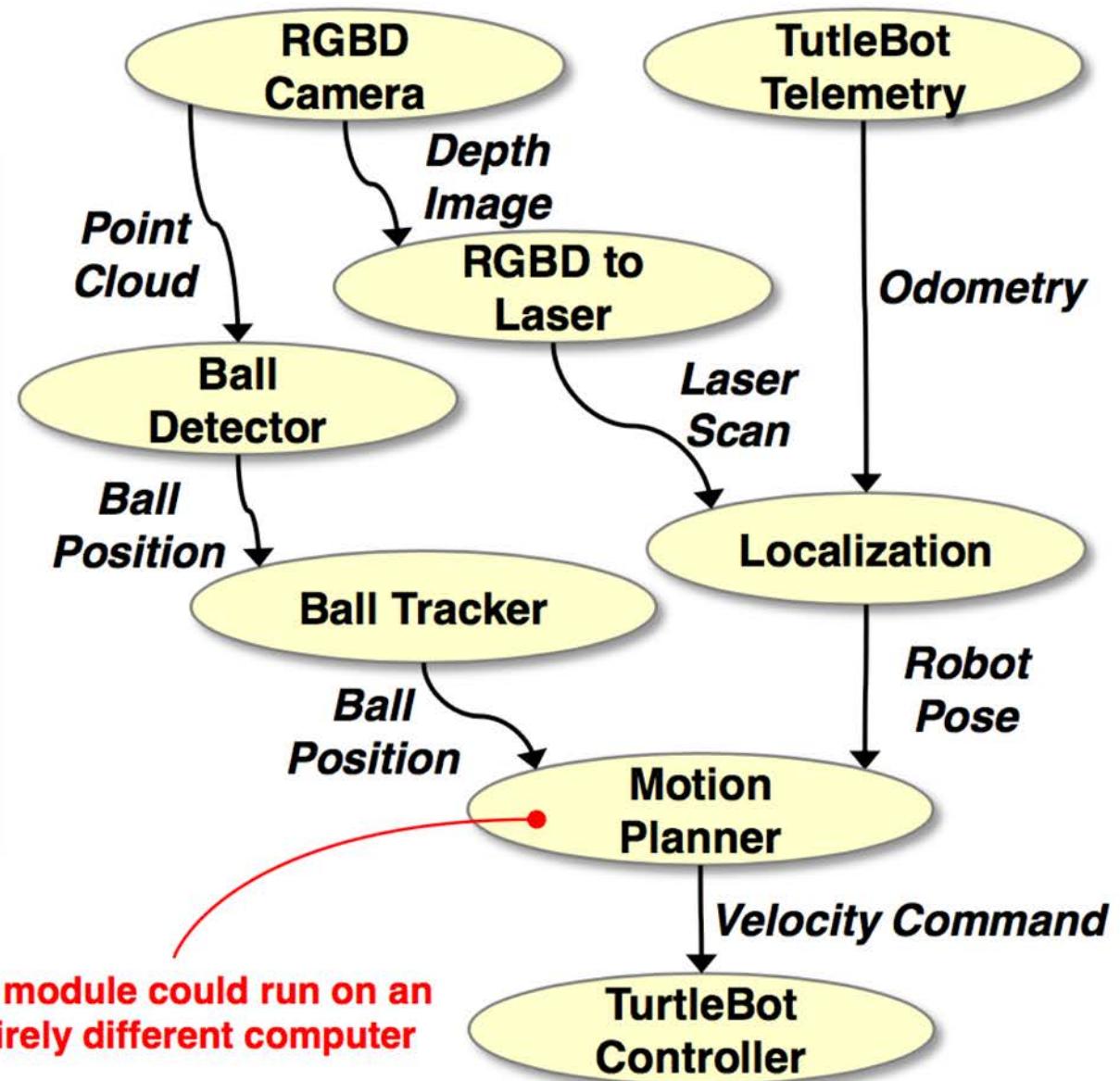
# Modular, Parallel



## Monolithic, Sequential

```
↓  
read_from_rgbd_camera(...)  
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update_ball_tracker(...)  
convert_rgbd_to_laser(...)  
    read_odometry(...)  
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send_motion_commands(...)
```

## Modular, Parallel



# ROS Philosophy

- **Peer to peer**  
Individual programs communicate over defined API (ROS *messages, services, etc.*).
- **Distributed**  
Programs can be run on multiple computers and communicate over the network.
- **Multi-lingual**  
ROS modules can be written in any language for which a client library exists (C++, Python, MATLAB, Java, etc.).
- **Light-weight**  
Stand-alone libraries are wrapped around with a thin ROS layer.
- **Free and open-source**  
Most ROS software is open-source and free to use.

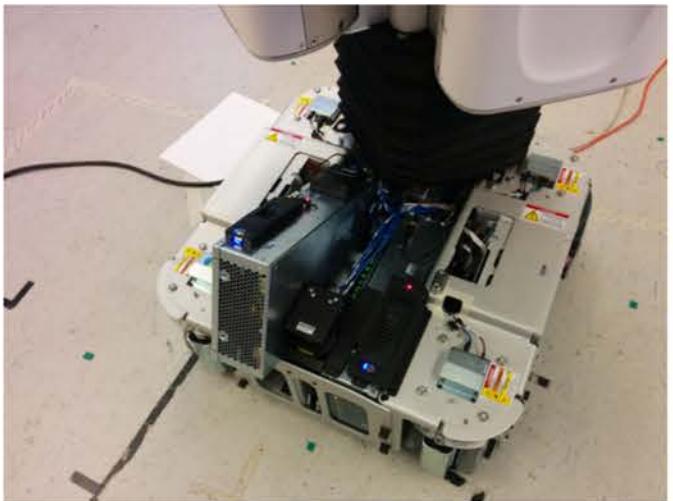
# Landmark Robots



# (some of the) ROS-based products available today



# Computational Changes



~1 kW



~20 W



~1 W



<< 1 W

# ROS History

- 2007 - Stanford Switchyard  
Part of the STanford Artificial Intelligence Robot (STAIR) project
- 2008 - Willow Garage increasingly assumes stewardship of ROS
- 2/2009 - ROS 0.4 (first “stable” release)
- 4/2009 - Lincoln starts using ROS
- 1/2010 - ROS 1.0
- 3/2010 - Box Turtle
- 8/2010 - C Turtle
- 3/2011 - Diamondback
- 8/2011 - Electric Emys
- 4/2012 - Fuerte
- 4/2012 - Tully Foote becomes ROS Platform Manager
- 1/2013 - Groovy Galapagos
- 2/2013 - ROS stewardship transfers to the Open Source Robotics Foundation (OSRF)
- 9/2013 - Hydro Medusa
- 7/2014 - Indigo Igloo



Willow Garage

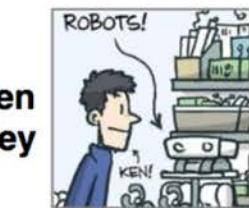


STAIR I

STAIR II



Morgan Quigley



Ken Conley



Tully Foote



Brian Gerkey



Open Source Robotics Foundation

# The Organization



## Open Robotics

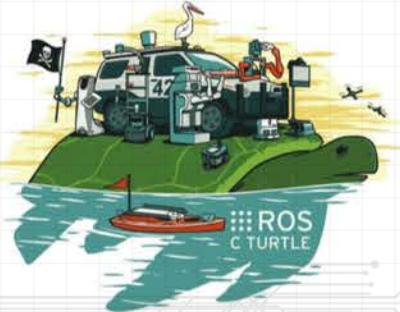
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We support the development,  
distribution, and adoption of open  
software and hardware for use in  
robotics research, education, and  
product development.

# ROS distributions



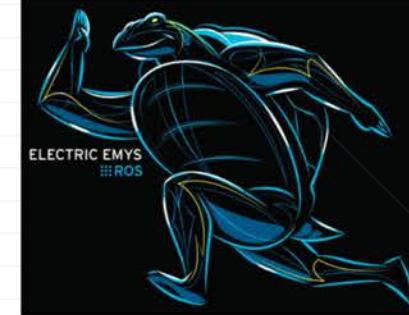
2010



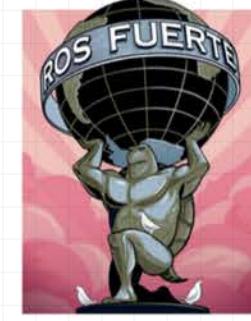
2010



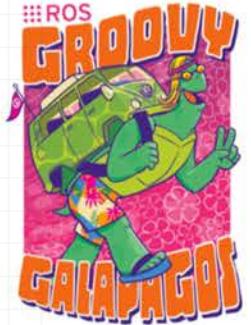
2011



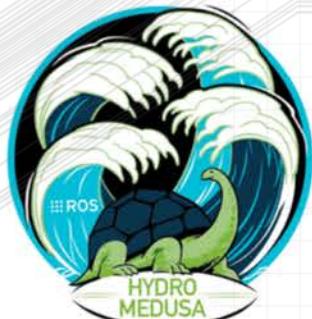
2011



2012



2012



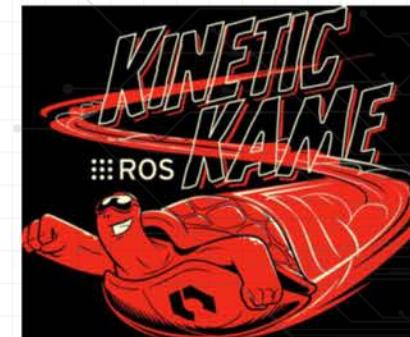
2013



2014



2015



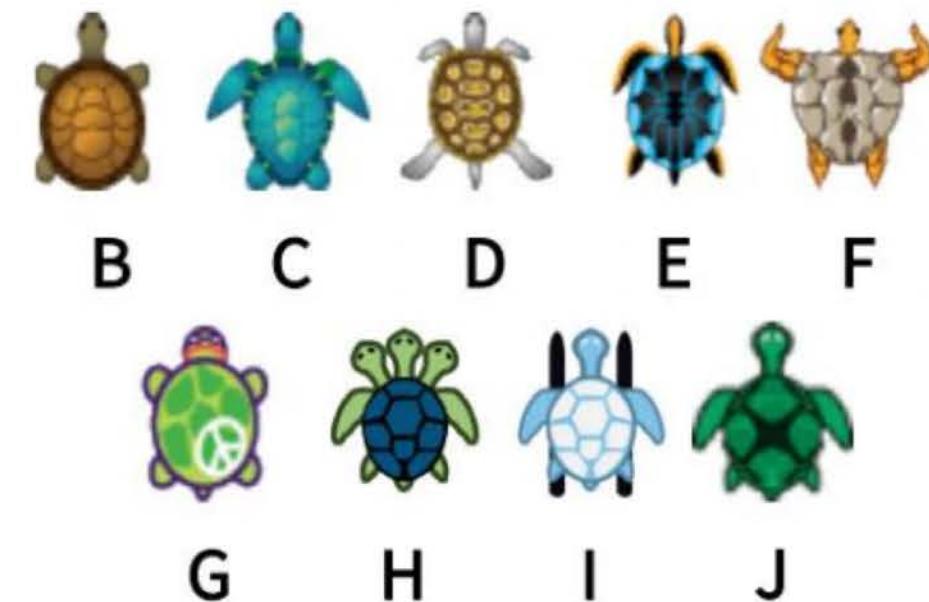
2016



2017



2018



# ROS Community: The “Who” and “How”

## Who Contributes to & Uses ROS?

- “Full-time” ROS developers
  - Open Source Robotics Foundation (OSRF)
- Independent contributors
  - Academia
    - Mostly graduate students
  - Industry
    - Robot builders & application developers
  - Hobbyists

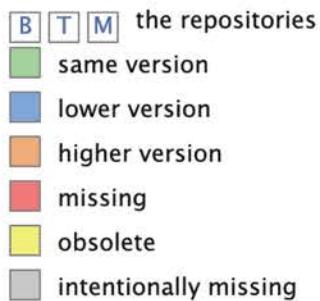


## How Do They Contribute / Coordinate?

- **ROS.org**
  - Wiki documentation & ROS standards
  - Special Interest Groups (SIG)
  - ROS Enhancement Proposal (REP)
  - ros-users mailing list
- **ROSCon**
- **Shared code repositories**
  - Linked by ROS.org, most moving to GitHub



Quick filter: \*, SYNC, REGRESSION, DIFF, BLUE, RED, ORANGE, YELLOW, GRAY, ORPHANED



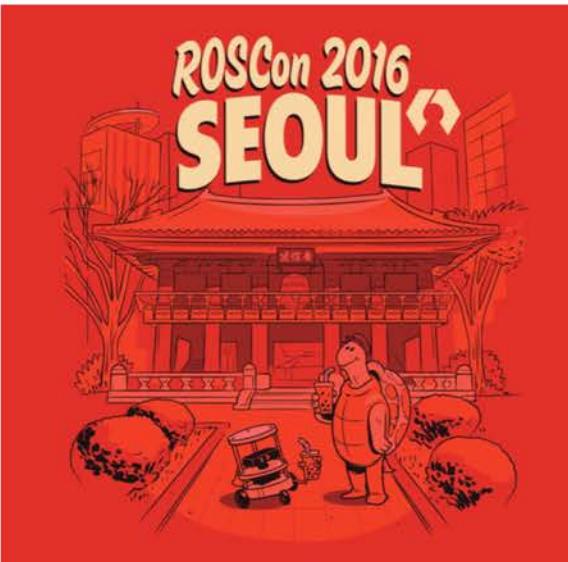
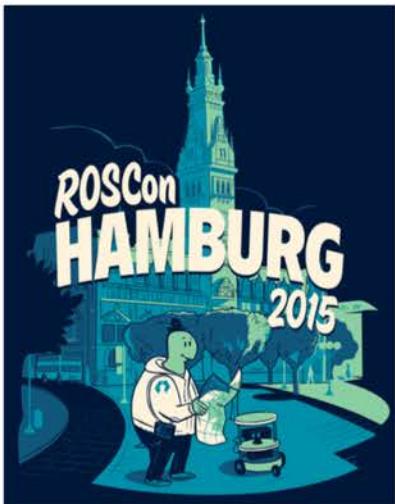
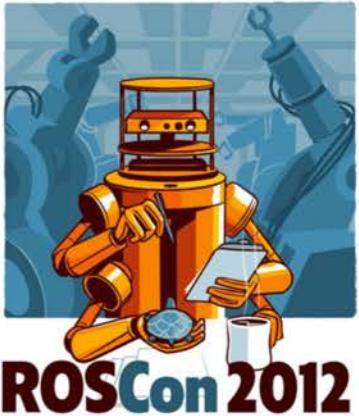
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showing 2667 of 2667 total

Name	Repo	Version	Status	Maintainer	Xsource 2666 2666 2664	X64 2632 2632 2631	X32 2626 2626 2625
abb	abb	1.3.1-1	developed	Levi Armstrong (Southwest Research Institute)	green green green	green green green	green green green
abb_driver	abb	1.3.1-1	developed	Levi Armstrong (Southwest Research Institute)	green green green	green green green	green green green
abb_irb2400_moveit_config	abb	1.3.1-1	developed	Levi Armstrong (Southwest Research Institute)	green green green	green green green	green green green
abb_irb2400_moveit_plugins	abb	1.3.1-1	developed	Levi Armstrong (Southwest Research Institute)	green green green	green green green	green green green
abb_irb2400_support	abb	1.3.1-1	developed	Levi Armstrong (Southwest Research Institute)	green green green	green green green	green green green
abb_irb4400_support	abb	1.3.1-1	developed	Levi Armstrong (Southwest Research Institute)	green green green	green green green	green green green
abb_irb5400_support	abb	1.3.1-1	developed	Levi Armstrong (Southwest Research Institute)	green green green	green green green	green green green
abb_irb6600_support	abb	1.3.1-1	developed	Levi Armstrong (Southwest Research Institute)	green green green	green green green	green green green
abb_irb6640_moveit_config	abb	1.3.1-1	developed	Levi Armstrong (Southwest Research Institute)	green green green	green green green	green green green
abb_irb6640_support	abb	1.3.1-1	developed	Levi Armstrong (Southwest Research Institute)	green green green	green green green	green green green
abb_resources	abb	1.3.1-1	developed	Levi Armstrong (Southwest Research Institute)	green green green	green green green	green green green
abseil_cpp	abseil_cpp	0.4.2-3	maintained	dfaconti	green green green	green green green	green green green
acado	acado	1.2.2-0	unknown	Ronald Ensing	green green green	green green green	green green green
access_point_control	linux_networking	1.0.15-0	maintained	Devon Ash	green green green	green green green	green green green
ackermann_controller	ackermann_controller	0.1.2-0	developed	Easymov Robotics	green green green	green green green	green green green
ackermann_msgs	ackermann_msgs	1.0.1-0	maintained	Jack O'Quin	green green green	green green green	green green green

# ROS Build farm and packages

# ROSCon 6 years





## Localization

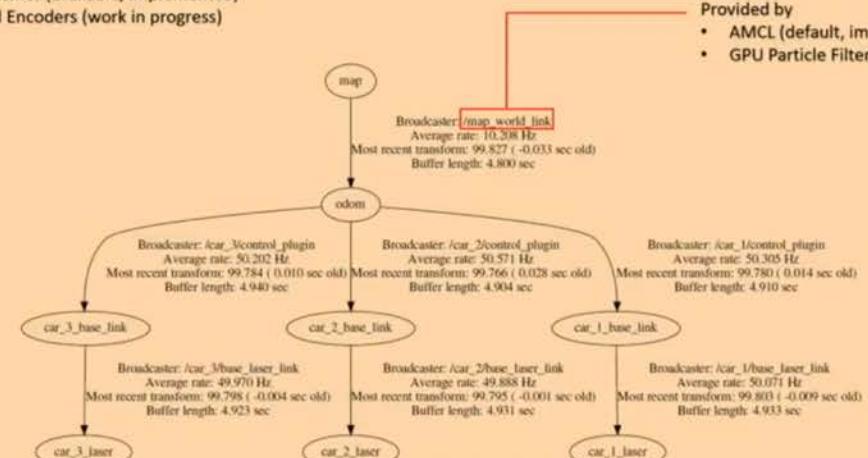
(Implemented for multiple vehicles)

### Odometry sources

- Gazebo (available, default option)
- Laser Scanmatcher (available, implemented)
- Virtual Wheel Encoders (work in progress)

### Provided by

- AMCL (default, implemented)
- GPU Particle Filter (available, tested)



[roscon.ros.org/2019](http://roscon.ros.org/2019)

#ROSCon @OpenRoboticsOrg

Ryohei Ueda, Kei Okada, Dirk Thomas, Vincent Rabaud, Daniel Stonier, Ipa-fmw, Kentaro Wada, Ioan Sucan, Ipa-fxm, Sylvain Joyeux, Tully Foote, Peter Soetens, Ugo Cupcic, Ken Conley, Dave Coleman, Jihoon Lee, Florian Weisshardt, K-okada, Ethan Rublee, Russell Toris, matlabbe, William Woodall, Mike Purvis, Michael Ferguson, Gael Ecorchard, Shunichi Nozawa, Aaron Blasdel, Alexander Bubeck, Mathias Lüdtke, Jack O'Quin, Ryan Pavlik, Dave Hershberger, rtv, Fumio KANEIRO, Isaac I.Y. Saito, Jonathan Bohren, kei.okada@gmail.com, Isaac Saito, Vladimir Ermakov, ipa-nhg, hattori, Alexander Tiderko, Shingo Kitagawa, watts, Armin Hornung, Ruben Smits, Piyush Khandelwal, tfoote, kwc, taylor, kei.okada, David Gossow, Damon Kohler, Troy Straszheim, Brian Gerkey, kanehiro, Sterling Orsten, Marcus Liebhardt, gerkey, Paul Bovbel, Markus Klotzbuecher, Davide Faconti, Adolfo Rodriguez Tsouroukdessian, Josh Faust, TheDash, Johannes Meyer, Justin Huang, Jorge Santos, shadowmanos, Troy D. Straszheim, Toni Oliver, David Kent, Martin Günther, Isaac I.Y. Saito, eitan, Felix Messner, hsu, youhei, Wim Meeussen, Daiki Maekawa, isucan, Austin Hendrix, alexv, wim, Florian Weißhardt, Andrea Censi, Alfred Team, wmeeusse, mihelich, gavanderhoorn, Tom Moore, notheworld@gsk.imi.i.u-tokyo.ac.jp, Fadi Furrer, Geoffrey Hunter, Marc Alba, Sachin Chitta, E. Gil Jones, tarukosu, abubeck, Stéphane Magnenat, Younghun Ju, Julius Kammerl, youhei@jsk.imi.i.u-tokyo.ac.jp, John Hsu, ueda, tailor, Karsten Knese, ipa-bnm, David Lu!, murooka@jsk.imi.i.u-tokyo.ac.jp, Eitan Marder-Eppstein, Tim Field, nakaoka, fmw-jk, Thibault Kruse, Shaun Edwards, jack.oquin, iori, sglaser, rsmits, Furushchev, ipa-ehr-fm, Nadia Hammoudeh García, corot, Thomas Moulard, Russell Taylor, Russell M. Taylor II, Mathieu Labbe, Peter Fenhaber, Jan Paulus, Benjamin Vaidi, dorodnic, manabu, Yuto Inagaki, Dorian Scholz, trainman419, Mikael Arguedas, Alex V, Richard Bormann, aginika, Rohan Agrawal, Doug Stephen, warataki, Jennifer Buehler, YoheiKakiuchi, Gaël Ecorchard, Ilya Lysenkov, Nick Hawes, ipa-goat, Geoffrey Biggs, Gassend Blaise, P. J. Reed, Mani Monajemi, Yuki Furuta, wattsk, Jeremy Leibs, Melonee Wise, Jihoon, Tony Baltovski, Georg Bartels, Dan Lazewatsky, Scott K Logan, Manos Tsardoulias, Russ Taylor, Gayane Kazhoyan, Takeshi Chiku, Erwan Le Huitouze, ipa-mig, fkanehiro, dan brooks, lorenz, blaisegassend, Dimitri Diakopoulos, thiagodefreatas, cob, Steven Kordell, blaise, Helen Oleynikova, Acorn, Kei OKADA, Francois Pomerleau, Morten Kjaergaard, Shun Hasegawa, straszheim, s-noda@jsk.imi.i.u-tokyo.ac.jp, Andy Zelenak, piyushk, Stephen Roderick, Levi Armstrong, vpradeep, davide, Dimitri, eisoku9618, dking, Patrick Beeson, Chad Rockey, Michael Burri, Markus Achtelik, iory, Tokyo Opensource Robotics Developer 534, DaikiMaekawa, pazeshun, Richard Vaughan, Ze'ev Klapow, Jeremie Deray, robot, Jose Luis Blanco, Satofumi KAMIMURA, Adam Leeper, Ethan, jamesb, Mario Prats, Jan Fischer, Bence Magyar, sjoyeux, k.saeki, dwlee, Fabien Spindler, Paul Mathieu, marshbur, Jose-Luis Blanco-Claraco, Jim Vaughan, meeussen, hudson, carlos3dx, ayton04, Mirza Shah, Mitchell Wills, Esteve Fernandez, kgadeyne, mmurooka, Mehmet Akcakoca, Isao Isaac Saito, Edward Venator, Andriy Petlovany, Sarah Elliott, ipa-fmw-ms, Matthias Hadlich, Mike Ferguson, François Pomerleau, Miquel Massot, icarpis, Kai Wurm, nlyubova, Robert Haschke, SawYer-Robotics, Chris Zalidis, furuta, Mark D Horn, agentx3r, ipa-cob4-2, Johannes Garimort, Shunichi NOZAWA, Ken Tossell, v4hn, sambrose, pomerlef, Marine CHAMOUX, Yusuke Niitani, Lorenz Moesenlechner, Christoph Rösmann, dg, Yohei Kakiuchi, Natalia Lyubova, Ioan A Sucan, Michael Görner, ipa-fxm-mb, xuefengchang, jrgnicho, Manos Nikolaidis, VahidAminZ, Reagan Lopez, Francis Colas, Kareem Shehata, Felix Mauch, evgeni.raikhel, Georg Heppner, Sebastian Kasperski, Thomas Roehr, Prasenjit Mukherjee, Mark Pitchless, Witalij Siebert, David V. Lu, Christopher Berner, tfield, vaughan, garaemon@gmail.com, Hunter Allen, mwise, ipa-taj-dm, jeremy\_asher, David Lu, toliver, Jannik Abbenseth, Bhaskara Marthi, sachinc, furuta@jsk.imi.i.u-tokyo.ac.jp, Jonathan Binney, rguzman, Takashi Ogura, Dorodnicov, Sergey, Maria Dimashova, blaise@eb33c2ac-9c88-4c90-87e0-44a10359b0c3, Wayne C. Gramlich, Samuel Charreyron, jfaust, fsi-takahashi, leus, ipa-led, Nikos Koukis, Devon Ash, dirk-thomas, Yosuke Matsusaka, Jean Sreng, Anqi Xu, durovsky, Phoenix, ipa-fxm-cm, chen, Denis Štogl, Caroline Pantofaru, Mickael Gaillard, Péter Fankhauser, Filip Novotny, 'Adrian, gmwe, cpc-pk, TSC21, RomanRobotnik, Morgan Quigley, enriquefernandez, Markus Bader, Isaac Isao Saito, Vincent Rousseau, Jon Binney, Yi Li, jleibs, Stuart Glaser, Ryosuke Tajima, MasakiMurooka, martiwer, alexcb, wheeler, mmwise, dash, Kanae Kochigami, Mark Horn, contradict, Vijay Pradeep, Steven Bellens, msh, Andreas Hermann, dekent, Stephan Wirth, virtubuntu 14.04, Steven Peters, Konstantin Schauwecker, JeremyZoss, Guillaume Walck, Kenneth Bogert, ipa-rmb, bhaskara, Shokoofeh Pourmehr, Elliot Johnson, ipa-jsf, Peter, Mathijs de Langen, Kirsty Ellis, Jose Luis Blanco-Claraco, Kochigami, Brandon Alexander, Ivan Dryanovski, Chris Dunkers, Akif, Acorn Pooley, shaun-edwards, nozawa, ipa-mig-mc, Paul Szenher, Felix Duvallet, Kristof Robot, JorgeArino, Eurecat Robotic Lab, Paul Bouchier, Jannik Buckelo, Beatriz Leon, inspectorg, Thomas Gubler, Ryan Gariepy, Jackie Kay, y22ma, weberh, Logrus, margueda, Shiqi Zhang, Nils Berg, ipa-cob4-5, Masaki Murooka, jnicho, pratkanis, Nate Koenig, Matthias Klatte, Ralf Kaestner, Ed Venator, rusu, jfaustwg, gm130s@gmail.com, b-it-bots, Naoya Yamaguchi, sfkw, seeger, rosen, eus, hersh, aangerma, YoshuaNava, JSK applications, FernandezR, croesmann, vrabaud, Jochen Sprickerhof, David V. 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Hoorn, tsuda, sachinchitta, hsujohnhsu, chen.jsk@gmail.com, Ted Miller, Peter Weissig, Marc Bosch-Jorge, Jorge Santos Simón, Jesper Smith, juliano, eacousineau, Wouter Caarls, HRP2, Geoff Biggs, wnowak, s-noda, ruipimentefigueiredo, paepcke, ipa320, ipa-srd-rd, fspindle, ethanrublee, Sacha Aury, Osiron007, Jonathan Meyer, Georg, snilsson, ipa-frm, iKrishneel, eraikhel, Siddhartha Banerjee, Mehdi Tili, Matthew Hansen, Jorge Arino, Henning Deeken, Armstrong, Levi H., Andreas, joq, jbinney, eoleynikova, cob3-5, ipa-taj, fmw-ss, ahb, Tokyo Opensource Robotics Programmer 534o, Stu Glaser, Pato, pissaris, ohara, dani-carbonell, Maxwell Svetlik, Matteo Leonetti, Jonathan Mace, Ha Dang, Christian Ehrmann, teddy, rjingar, jonbinney, ipa-raw3-3, bencohen2, Sergey Dorodnicov, Philipp Schillinger, Murilo F. M, Dash, Benjamin Singer, sukha-cn, jon, Yann Sionneau, Roman Navarro Garcia, Nathan Mertins, Karel Kosnar, Hamdi Sahloul, Enrique Fernandez, spkordell, rdiankov, plnegre, mikepurvis, ipa-cob4-1, fevb, akohlmey, Your full name, Wolfgang Merkt, Oleg Alexandrov, Lucian Cucu, Lars Pfotzer, Christian Connette, Arjun, wg\_cmeyers, ipa-mdl, atp, Shane Loretz, Murilo FM, Mike Hamer, Michal Staniaszek, Daniel Maier, Chittaranjan Swaminathan Srinivas, Ben Charrow, troy d. straszheim, tfield@eb33c2ac-9c88-4c90-87e0-44a10359b0c3, skyzorg, kruset, ipa-ehr, furushchev, Thiago de Freitas Oliveira Araujo, Karsten KNESE, Ilya, Christos Zalidis, jrutgeer, dave, Torsten Andre, Mikael ARGUEDAS, Keith Hughes, Julian Cerruti, Hunter L. Allen, Grommetox, Felipe Garcia Lopez, Chris Lalancette, Atsushi Watanabe, pmukherj, inagaki, cob3-1-pc1, brudder, Tony Pratkanis, Timo Hackel, Matei Ciocarlie, Claudio Bandera, Chris Lewis, Aris Thallas, Akif Hacinecipoglu, wcaarls, uavc, manabu1118@gmail.com, ddevries, ShotaroTerato, Jose Rapado, Jim Rothrock, Eric Perko, Christoph Sprunk, Charles Lesire-Cabaniols, toni, roseus, ipa-cob3-7, gawela, elliotjo, ehberger, ahendrix, RobotnikRoman, Pulse Developer, MRP2 Dev, Kelsey, Kazuya.N, Jia Pan, Jenkins, Erwin Aertbellen, Eric Berger, Dani Carbonell, Arne Hitzmann, Allison Thackston, ryang, rdelgadov, mkjaergaard, leonidk, dthomas, cbridge, atenpas, Surya Ambrose, Steffen Rühl, Mathieu Labb  , Gary Servin, Benjamin Chr  tien, Aurelien Yol, Arguedas Mikael, tsv, stachnis, mirzashah, mikehosmar, konolige, ipa-cob3-8, dgossow, Sven Schneider, SparusII, Mike Irvine, Ken Anderson, Kaijen Hsiao, Denis Dillenberger, David Landry, rospeex, nao, mmurooka, kawasumi, jbohren, iwaishi, ipa-rmb-fj, Raphael Zack, Networked and Embedded Systems - Alpen-Adria Universit  t Klagenfurt, Kartik Mohta, Jan Winkler, JSK-PR2, Hiroaki Yaguchi, George Stavrinou, COB3-Manipulation, Bota Hu, AndriyPt, yujin, kohn, jamesbowman, ipa-cob3-6, christoph, chen.jsk, archielee, Siegfried-A. Gevatter Pujals, ShadyLady, Scott Nieku, Rodrigo Alexis Delgado Vega, Rocketmagnet, Rein Appeldoorn, Peter Fankhauser, Nikolaus Demmel, Nicolas Goossaert, Hans Gaiser, Frantisek Durovsky, Dan, v01d, user, robotpilot, pmihelich, mikita, jkammerl, huey, but-spanel, barmasa, Victor Lopez, Surya AMBROSE, Roman Bapst, Rob Wheeler, Rajiv Jingar, LucaLattanzi, Lorenz M  senlechner, Lior Ramati, Francisco Vina, Florian Lier, Derek King, COB3-Navigation, Alexander, mdim, lokada, kwc@eb33c2ac-9c88-4c90-87e0-44a10359b0c3, jiangjun, ipa-tys, ipa-srd, ipa-jsf-mf, gjones, artivis, Winfried Baum, Martin Pecka, Lucas Walter, Joshua Hampp, Ivor Wanders, Iori Kumagai, GuiHome, Fran  ois-Michel De Rainville, Bando Masahiro, rohit chandra, ravin, kazuto, jhoonl, jenkins, ipa-ehr-mk, ipa-fmw-sh, hand, guihome@wanadoo.fr, baishi.bona@gmail.com, Timo R  hling, Sam Pfeiffer, Robert Krug, Nuno Marques, Mike O'Driscoll, Jeremy Zoss, Eric Cousineau, ElenaFG, Damjan Miklic, Armstrong, Levi H, thjc, snozawa, sharif, nrgadmin, liminglong, ishiguro, ipa-fmw-ws, ipa-cob3-3, devbharat, Vahid Aminzadeh, Timo Hinzmann, Takasugi Noriaki, Gary Bradski, Felix Kolbe, Eric Tappan, Alexander Reimann, uh-reza, turtlebot, trul, sukha, sain, pyup-bot, pooya, nir.cohen, Iggerardi, kirstyellis, kevinwwatts@gmail.com, katsumik, ipa-cmm-mm, h-kamada, doudou, bensonl, V  ctor L  pez, Thomas Solatges, Rich Mattes, Ricardo Delfin Garcia, Paloma de la Puente, Noriaki Takasugi, Michael Stoll, Max Schwarz, Matt Vollrath, Marcel Stuetgen, M.H.Kabir, Karl Glatz, Jon Dybeck, John He, Jerry Towler, Jean-Baptiste Passot, James Bowman, JSK User, Ian McMahon, IPR-SR2, Bobby, Atsushi.tsuda@gmail.com, =, winston, summit, sdorodni, kurtkonolige, kohlbrecher, jon-weisz, ipa-cob3-9, fmw-hb, eitanme, cpc, asorian01, Todor Stoyanov, Pavel Vechersky, Mathieu Gautier, Markus Bader @ munin, Marco Bezzon, Jorge Caf  ardo Alastuey, Jivko Sinapov, Georg Wiedebach, Dmitry Rozhkov, Administrator, robotictang, rob\_wheeler, nanowork, lsouchet, ipa-cob4-4, fujii, borland, ban-masa, babaksit, Yutaka Kondo, Yu Ohara, Takahiro Miki, Stefan Osswald, Sourav Senapati, PaulBouchier, Pascal Becker, Maximilian Sieber, Lucid One, Kohei Kimura, Kent, nekura, Kent, sommer, Joan Pau Beltran, Hugo Elias, Florian K  hler, Dariush Forouher, Daniel Solomon, Cedric Pradalier, Brice Rebsamen, AndyZe, Alwin Heerklotz, 7675t, tnaka, talregev, stuglaser, noriaki, neobotix, maxsvetlik, markusachtelik, ipa-ehr-ipa-cob4-6, nkaraoguz, hiDOF, goa, bnm, b-it-bots-secure, ZdenekM, Yannick Jonetzko, Playfish, Mustafa Safri, Jorge Nicho, Joerg Mueller, JakobEngel, Hand, Georgiy Frolov, Garrett Warnell, Felix, Chris Burbridge, Aris Synodinos, Andy McEvoy, zhihui, wwwrob, rawr, Administrator, nkoenig, morisawa, marbosjo, joselusl, fdurovsky, corb555, bordicon, au@eus, atiderko, abencz, YutoUchimi, Robotnik, Radu Rusu, KristofRobot, Kim Min Soo, Jun Inoue, Javier V. Gomez, GaiTech-Robotics, Enrique Fern  andez Perdomo, Elena Gambaro, Christian Rauch, Chris Mansley, Carlos Villar,



Boris Gromov, Andreea Tulbure, Andreas Antener, Alexis Ballier, Alexander Schaefer, Aaron Hoy, Aaron Denney, walter, vijaypradeep, uid500, uh, t.chiku, noda, mhkabir, ipa320-cob3-6, ipa-cob3-2, iMoby, hughie, hassan, framegrabber, dg-shadow, citay, Ubuntu14.04.3-64bit, Rik Baehnemann, Nir Cohen, Nicholas Alton, Mohammed Kabir, Miklos Marton, Michael Stypa, Micha Rappaport, Matt Curfman, Kazuya N, Jeff Schmidt, Hakan, David Anthony, Dane Powell, Curt Meyers, yuqian, trevorjay, syrnick, sxtejeda, sniekum, root, rmb-om, rethink-kmaroney, local\_admin, ktossel, ipa-goa-sf, ipa-cob4-8, hyatt, grisetti, fsuarez6, dlu, convert-repo, cob4-1, bouchier, bona\_desk\_1, beatrizleon, baxter, autolab, andymcevoy, aau-ros, Silvio Traversaro, Shadow Hand at Ulster, Shadow Hand at Bielefeld, Satoshi Iwaishi, Samuel, Sam, S Roderick, Riccardo Spica, RB1, Pramuditha Aravinda, Michael Sands, Lorenz Mösenlechner, Lorenz Meier, Kris Kozak, Kevin C. Wells, Jakob Schwendner, JAXON, Hannes Sommer, Felix Gruber, Ethan Ruble, Dereck Wonnacott, Christopher Baker, CCNY Robotics Lab, Brian Jensen, Brett Grandbois, Archie Lee, Applications, Adrian Cooke, yusuke furuta, weigle, uh-klk, shoi hatakeyama, orbbec, ob-tim-liu, lorenzoriano, jprod123, ipa-josh, ipa-fxm-db, humio, fcolas, bh5man, yoyol, alex, Yoonseok Pyo, Tatsuya Ishikawa, Stefan Kohlbrecher, Shaghayegh, Satoshi Otsubo, Neuhold Daniel, Mihai Pomarlan, Michael Jae-Yoon Chung, Marco Esposito, Manos Stergiadis, Kevin M. Godby, Kai Franke, JonathanMace, JerryLiu, Haoyao Chen, Eric Renor, Li neemans, Edly, Dorian Scholz, Dorian Scholz'n, Build Tools, youbot, y-tnaka, xaxxontech, tsuji, tdeletaet, straszheim@eb33c2ac-9c88-4c90-8e0-44a10359b0c3, srd, ressac, pcler, natepak, morgan\_quigley, kaijenhsiao, ipa, ik0313@gmail.com, Janne, gregory, g\_marcz, fmw-jil, hou, etha, dhod, cob4-7, cmdunkers, chrisrick, calibration, bponsler, babak sistani zadeh, asimay, asadat, andreas, administrator, Yumi, Thomas Zwoelfer, Tamaki Nishino, Shadow Hand, Romain Thibaux, Rolando Fernandez, RoboPeak Public Repos, Remo Diethelm, Raghavender Sahdev, Philipp, Niklas, Marco Dierschke, Marco Arruda, Mac Mason, Lucas Chiesa, Laurent GEORGE, Konstantinos Chatzilygeroudis, João Sousa, JoseRobotnik, Jonathan Jekir, Jntzko, Janosch Nikolic, James Servos, Jae Yeong Lee, Hunter Laux, Gheorghe Lisca, Eric, Elias Marks, Chris Mueller, Chittaranjan Srinivas Swaminathan, Aqua, Andrew Glusiec, Alexis Maldonado, Alex Brown, wesleypcchan, wesley, thiagodefreatas@gmail.com, rocknrolla, probablydavid, pgorzak, orikuma, mpurvis@clearpathrobotics.com, mig-jg, mig-em, mccallus, mblanton, kindsenior, k.natsusako, jskuser, jclark, jakan2, ipa-cob3-4, gsibley, fmw-rs, dist, Yujin, William Xie, Victor Murray, Tobias Tueyalue, Tinne De Laet, Thorsten Kannacher, Tanja Baumann, Stefan Fillafer, Sharon, PetaroMitaro, Paul Chavent, Naveed Usmani, Murilo F.M, Matthew Woehlke, Martin Schuster, Martin Cote, MRP2 Development, Luis Rodrigues, Linquize, Ling, KOYAMA Ryo, Jan-Niklas Nieland, Isura, Hugo A. Garcia, Hervé Audren, Heecheol Kim, Hans-Joachim Krauch, DominickVanthienen, Dominic Jud, Christoph Mark, Charles Duhadway, Brad Davis, Benny, Beat Küng, Alexis Girault, Affonso, Guilherme, 'Austin Hendrix, velinddimitrov, v-lopez, skinner, ser=egiljones, rtmrosrobotics.testing@gmail.com, relrotciv, ptrkfry, pratkanis@willowgarage.com, pantofaru, nj1407, narora1, kumsu, kint.zhao, ipa-goa-wt, ipa-goa-aa, ipa-fmw-js, iou16, h.mikita89, filipnovotny, dawonn, cob4-2, buildbot-squirrel, bsteder, brics, arjungm, acfloria, Zachary Taylor, Yoan Mollard, XuHao, Wayne Gramlich, Velin Dimitrov, Tobias Fromm, Timm Linder, Suat Gedikli (gedikli), Suat Gedikli, Steven Kauffmann, Stasinos Konstantopoulos, Shengye Wang, Scott Hassan, Ryo KOYAMA, Robert Lynch, Rob Linsalata, Renaud Dube, Ramon Wijnands, Peiyi Chen, Patrick Doyle, Patrick Chin, Pablo Iñigo Blasco, Oleg Sinyavskiy, Nicolas El Hayek, Nathan John, Moju Zhao, Minglong Li, Mike Hosmar, Michael Brindle, Meyer, Jonathan W, Martí Morta, Lluís Salord Quetglas, Libor Wagner, Lewis, Chris L, Kathryn Baldauf, Kabir Mohammed, Josh Langsfeld, Johan Robben, Jenny Owen, Javier V. Gómez, Jason Mercer, Jaime Pulido Fentanes, Igor Zubrycki, Ibrahim Awwal, Hercules, Gregory Jefferis, Forrest Rogers-Marcovitz, Federico Ferri, David Hodo, Craig Lilley, Clay McClure, Christopher Wecht, Carlos Costa, Basheer Subei, BWI, Antonio El Khoury, Andy Wilson, Andreas Wachaja, Allan E. Conquest, Alexander Sorokin, Alonso Labady, y-yosuke, sabrina-heerklotz, ros-industrial, reed, pszenher, otim, nalt, mquigley, mizmizo, mig, mcantero, lovelace, john, jlaforga, jenkinshr, jack-oquin, ipa-fez, hrpuser, hemes, gunter, gerkey@willowgarage.com, gedikli, frosthand, fig, edgarriba, chiwunau, chikuta, chenju, brice rebsamen, boyoon, bibarz, austinrobot, antonydeepak@gmail.com, Xuefeng Chang, William, Thomas Moinel, Thiago Araujo, Summit XL Steel, Shintaro Hori, Sameer Parekh, Sahloul, Peter Mitrano, Nikolas Engelhard, Nicu Sturca, Mirza A. Shah, Matteo Munaro, Martin Ankerl, Mark Johnston, Léonard Gérard, Luís Rodrigues, Luka Čehovin, Lucas Souchet, Luc Bettaleb, Lawrence Kwan, Koen Lekkerkerker, Kevin Wells, Jordan Lack, JoRobot, JimmyDaSilva, Jason Gassaway, Jamie Snape, James Goppert, JRombouts, Issac Trott, HiroyukiMikita, Genevieve & Ugo, Francisco, Forrest Voight, Flavio Fontana, Felix Endres, Emili Boronat, Elad Zucker, Di Sun, DavidVLu, Daniel Maturana, Daniel Axtens, Christina Gomez, Chris Foster, Charles Lesire, Arn-O, Alpha laptop user, Alessandro Francescon, , z, xuhao, xaedes, wud, wkentaro, uh-mb, tyuownu, terasawa, sturm, srs, smichaud, ser=aleeper, selliott, rusu@eb33c2ac-9c88-4c90-8e0-44a10359b0c3, rosen.diankov@gmail.com, rosen.diankov, ros, robertogl, raw3-6, ravinld@gmail.com, pbesson, orhangazi44, nakanish, murase@jsk.imi.i.u-tokyo.ac.jp, makcakoca, m117120@gmail.com, loganE, kphawkins, karlyeurl, julien.waechter, ipa-flg, hisamatsu, hes3pal, henhenhen, frm, fretzagi, estumm, eriksen, erik, demo@youbot-brs1-2-pc1, cwecht, cob3-1-pc2, berger, auboliuxin, aub, arsi, allenh1, alab288, abencz@clearpathrobotics.com, aba, Yusuke Furuta, Yuri Gavshin, Your Name, YoonseokPyo, Valerio De Carolis, Tu-Hoa Pham, Tomas Petricek, Thomas Timm Andersen, The Gitter Badger, Terasawa, Sr41, Spyros Maniatopoulos, Spencer Jackson, Siteleaf, Simon Schmeisser (isy vision), Simon Gene Gottlieb, Shadow Hand at Akron, Sergi Foix, Sergey Alexandrov, Sebastian, Scheik, Ryohhei ueda, Ryan Sinnet, Rong, Robohacker, Rob Wilson, Rachel Brindle, RTV, Pierick Koch, Philipp Kruesi, Peter Nemeth, Nils Bore, Nicolas Alt, Neal Seegmiller, Murilo F. M., Mr-Yellow, Mitsuharu MORISAWA, Mike Krainin, Mike Koval, Michael Carroll, Michael Bowler, Mehdi Benallegue, Matthias Nieuwenhuisen, Matt Derry, Luke Tokheim, Levon Avagyan, Laura Lindzey, Kunihiro Yasuda, Konrad Banachowicz, Koen\_Buys, Kel Guerin, Jeff Delmerico, James Garrett, Jafet Villafranca, Jack Thompson, Ish Sanchez, Ian Danforth, Hodorgasm, Gustavo Velasco Hernández, Gian Diego Tipaldi, Gabor Meszaros, Erik Karul, Emerson Ferreira, Doug Sievers, Dominik Klein, Dave Niewinski, Daniel Miller, Christopher Dunkers, Chris Smith, Chris, Carlos Agüero, Carlos Aguero, C. Barrett Ames, BryceVoort, Bruno Lacerda, Brindle, Bolkar Altuntas, Bill Benson, Bert Willaert, Barrett, Andres Stepaniuk, Alexander Pekarovskiy, AlexReimann, Alex Millane, 708yamaguchi, zhihao\_iscas\_ac\_cn, zhibo, yoshimalucky, wesleyc, warnellg, ted-miller, t.yoshikai@gmail.com, t-ito, simonschmeisser, simonlynen, shermansxt, rosewall, rgariepy, rdam, raw3-1, pr2admin, phussey, nate koenig, mrodriguez-robotnik, mmacsek, micros-uav, markpitchless, lucasb-eyer, libo24, kurt, kuroiwa, kriskozak, kintzhao, kids-bytes, kevincwells, jtyler, jrom, jazzfunk, ipa-uh, ipa-jenkins, ipa-goa-jh, inoue hirohumi, ik0313, hrp2user, h.mikita89@gmail.com, grxuser, doctorseus, dneuhold, denis, davidlu, davecrawley, dan@lazewatsky.com, damonkohler, commaster90, cob\_hwาระ\_test, cob4-10, chapulina, bwi, boris-il-forte, bener, bbrieber, banerjs, bagside, au@pr1012, atp42, aqua, Yujin Robot, Windel Bouwman, Wermelinger Martin, Vojtech Novak, Vladislav Tananaev, Vladimír Petrik, Victor Lamoine, Ugo Cupcic ugo@shadowrobot.com, Ubuntu user, Tom Gehrke, Titus Cieslewski, Tim Taubner, Tim Clephas, Till Hofmann, Thomas Moore, Thomas Fischer, TUG-DESTOP, Suzanne G, Stephan, Stefan Oßwald, Smart Robotic Systems, SimonEbner, Simon Schmeisser, Shadow Hand at SynTouch, Shadow Hand at IFMA, Shadow Hand at GSC, Scott Livingston, Sarah Osentoski, Samir P, Samir Benmendil, Russell Taylor, Rui Miguel Horta Pimentel de Figueiredo, Ruben Burger, Ruben, Robert Codd-Downey, Richard-Lab, Richard Mattes, Raven Black, Rares Ambrus, Pierre Willenbrock, Perry Franklin, Paul Milliken, Paul Dinh, Patrick Mania, Pat, Pascal Gohl, Pablo Urcola, PR2 application, Navigation, Nathan Burke, NXO customer account, Mike Bosse, Miguel Sarabia del Castillo, Mickaël, Michael Korn, Michael Hwang, Megacephalo, Marley, Markus Eich, Markus Bajones, Marc Bosch, Marc Bestmann, Ludovico Russo, Lucie Belanger, Len Zhong, L0g1x, Kyle Maroney, Konstantina Kastanara, Komei Sugiura, Ken Conely, Kazuya Natsusako, Karel Košnar, Juan Sebastian Casallas, Juan Laforga, Josh Villbrandt, Josep Bosch, Jose Luis Blanco Claraco, Jonathan Wade, Jim Radford, Jelle Feringa, Javier G. 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Jeremy Laviole, Jep, Jenny, Jean-Francois Dupuis, Janko Petereit, Jan Ciger, Jacob Minshall, JSK, IsaacSaito, Interactive Manipulation, Ilia Baranov, Igor Rodriguez, Ian Chen, IRISS, Huey, Hendrik Wiese, Halton Huo, Hajime SAITO, Gustavo N Goretkin, Guillaume JACOB, Gregory Hitz, Girts Linde, Gianni Borghesan, Gerard Canal, George Laurent, Gennaro Raiola, Fred Proctor, Francisco J Perez Grau, Francesco Romano, Francesc Bonin Font, Florian Keßeler, Federico Boniardi, Fabian Wiesel, Eduardo Cáceres, Dustin Gooding, Douglas Stephen, Dongwook Lee, DevonAsh, Denis Romanchuk, David Watkins, David Ryskalczyk, David Hershberger, Daniel Mirota, Daniel Jartoux, Daniel Aden, Dangr, Damien Smeets, DaMal0, Colin Lea, Cody, Christopher-Eyk Hrabia, Christian-Eike Framing, Charles Prévôt, Caspar Reist, Carlos Rosales, Carlos M. 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Thank you! 3

2817 Authors (average 74.6 commits per author) of commits in Git repos with source entries  
in the Indigo rosdistro



# Current Status of ROS 2 - Hands-on Feature Overview

## Why ROS ?

### Use-case / basic requirements

- ▶ Teams of multiple robots
- ▶ Small embedded platforms
- ▶ Real-time systems
- ▶ Non-ideal networks
- ▶ Production environments
- ▶ Prescribed patterns for building and structuring systems



December '17



July '18



December '18

Dashing  
Diademata

May '19

### History

- ▶ Development started in 2014
- ▶ First stable release in December 2017
- ▶ First LTS release planned for May 2019



[http://design.ros2.org/articles/why\\_ros2.html](http://design.ros2.org/articles/why_ros2.html)  
<https://index.ros.org/doc/ros2/Roadmap/>

A relevant degree is required, for instance in Computer Science or Engineering. A background in Robotics/Computer Vision is desirable, **while knowledge of the Robot Operating System (ROS)**, the Point Cloud Library (PCL), or the Open Source Computer Vision Library (OpenCV) is a big plus.

Goal of this PhD is to study, **design and build novel industry-level software based on ROS or ROS-Industry** which is modular, reconfigurable, adaptive, easy to use to integrate and control various robotic systems.

**\*\* Job Requirements \*\***

- Experience with software development and integration preferably in a Linux environment
- Proficient in C, C++, Python and Matlab
- **Those with past experience using ROS will be preferred**

The candidate must be a **proficient user of C/C++ and ROS and any relevant computer vision library (e.g., ViSP, OpenCV, PCL)**. Scientific curiosity, large autonomy and ability to work independently are also expected.

**\*\* Required Qualifications \*\***

- A university degree (Master or Diplom-Ingenieur)
- **Proven programming skills in Matlab, C / C ++, ROS**
- Good knowledge of cooperative software development with GIT or SVN

**Required Skills**

- \* MSc in Engineering / Computer Science or equivalent.
- \* Experience with Robotics
- \* **Knowledge about ROS (Robot Operating System) and CV.**
- \* Advanced experience with C++ and soft real-time programming.
- \* Team spirit and ability to work independently.
- \* Excellent communication skills, flexibility and creativity.



ROSCon 2015  
Hamburg, Germany

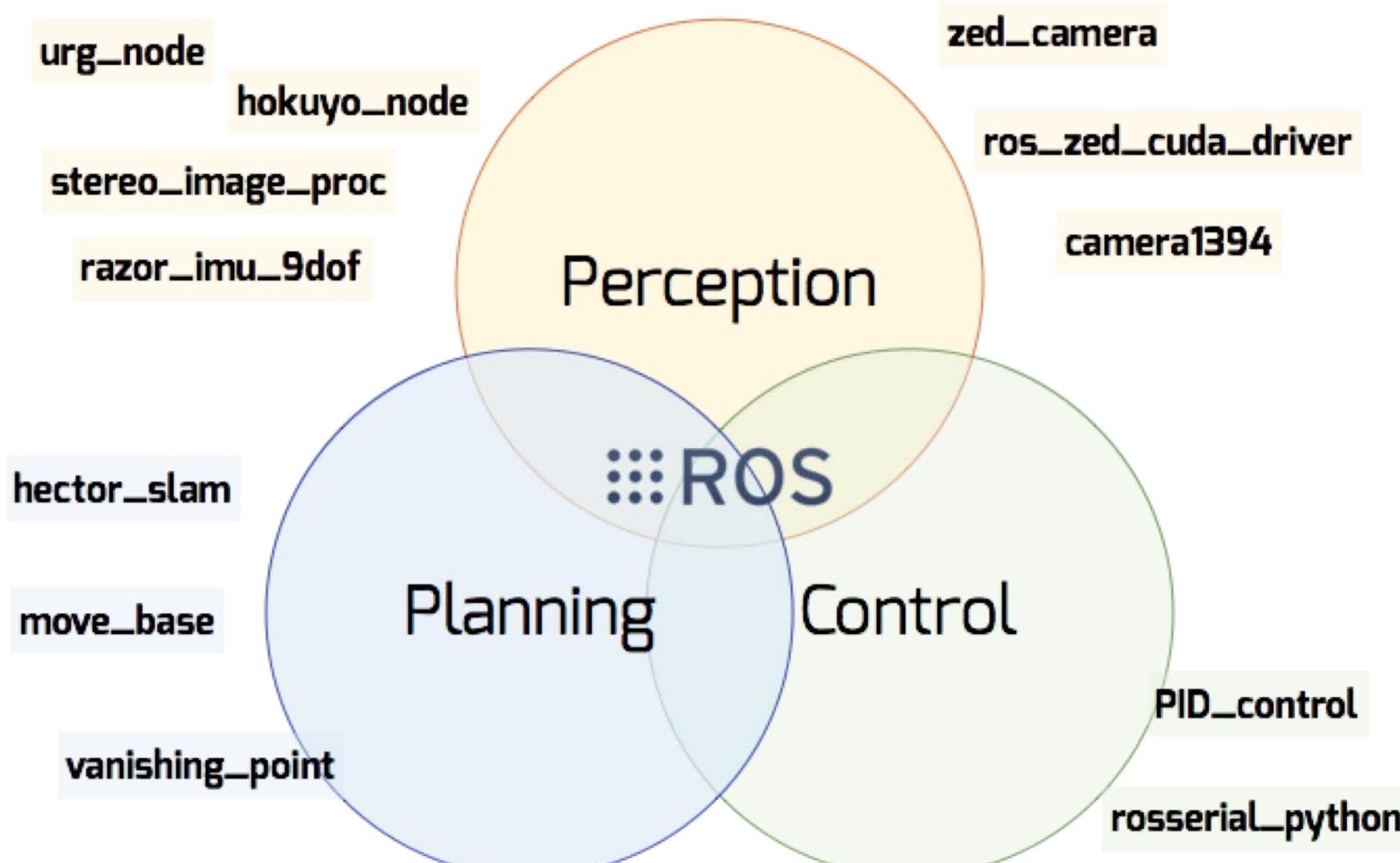
## AUTOMATED DRIVING WITH ROS AT BMW.

**MICHAEL AEBERHARD, THOMAS KÜHBECK, BERNHARD SEIDL, MARTIN FRIEDL,  
JULIAN THOMAS, OLIVER SCHEICKL.**

**BMW  
GROUP**

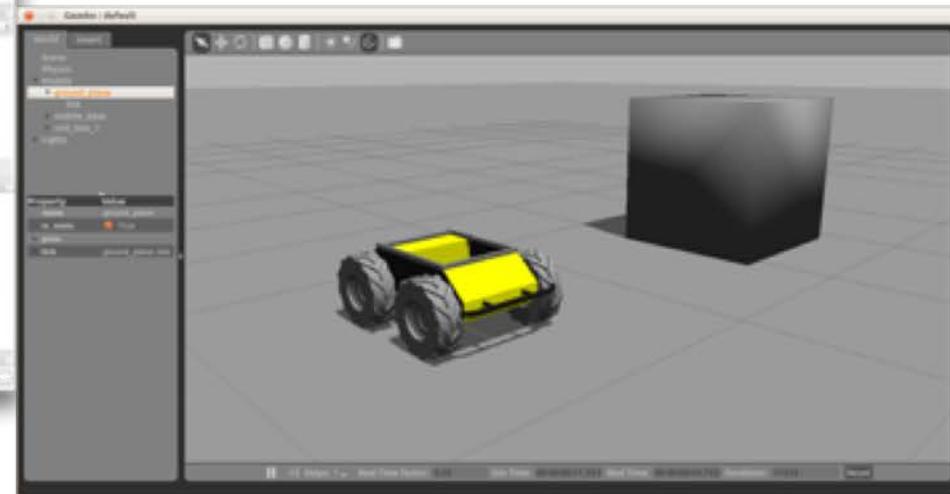
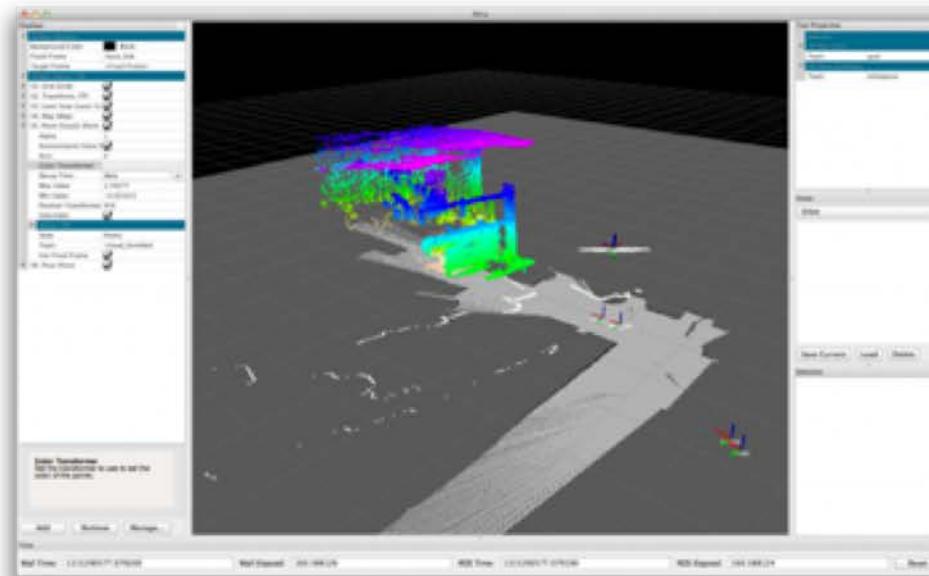
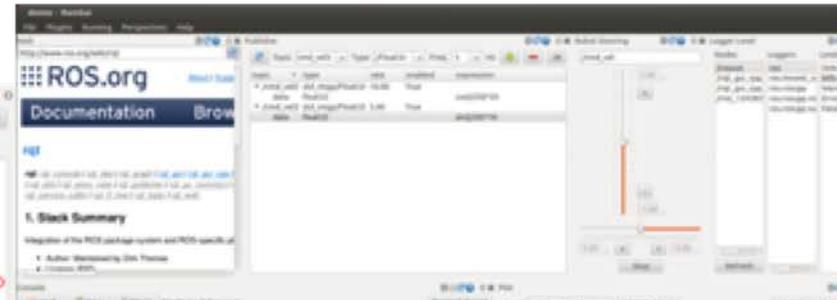
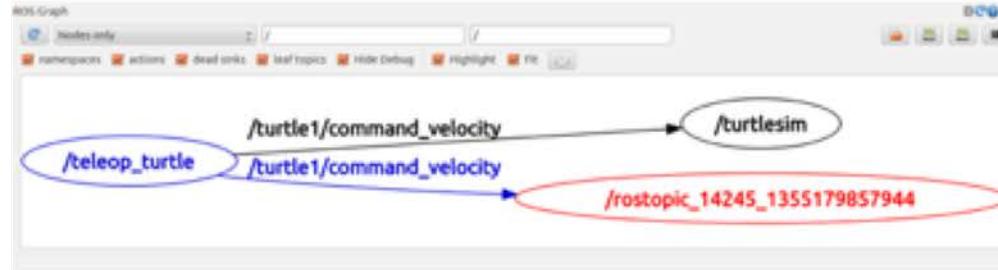


# ROS Capabilities



# ROS Tools

Visualization, debugging and diagnostics, logging, and simulation

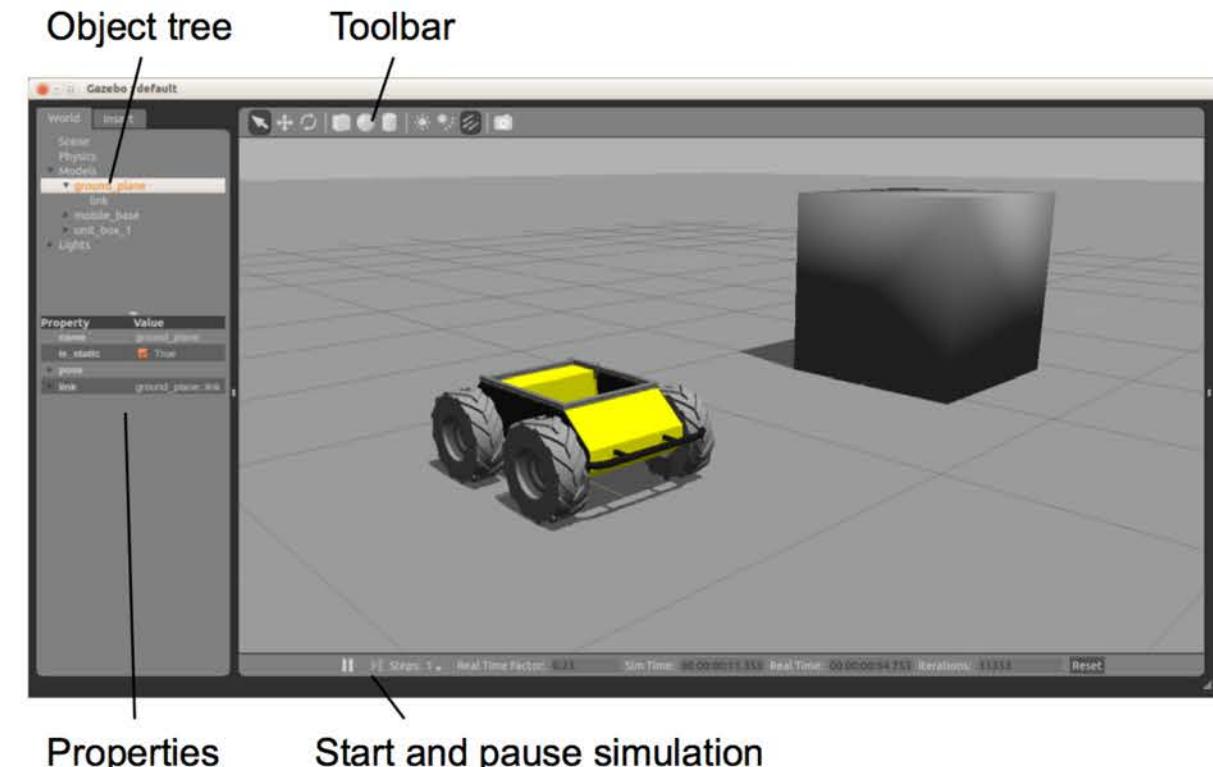


# Gazebo Simulator

- Simulate 3d rigid-body dynamics
- Simulate a variety of sensors including noise
- 3d visualization and user interaction
- Includes a database of many robots and environments (*Gazebo worlds*)
- Provides a ROS interface
- Extensible with plugins

Run Gazebo with

```
> rosrun gazebo_ros gazebo
```



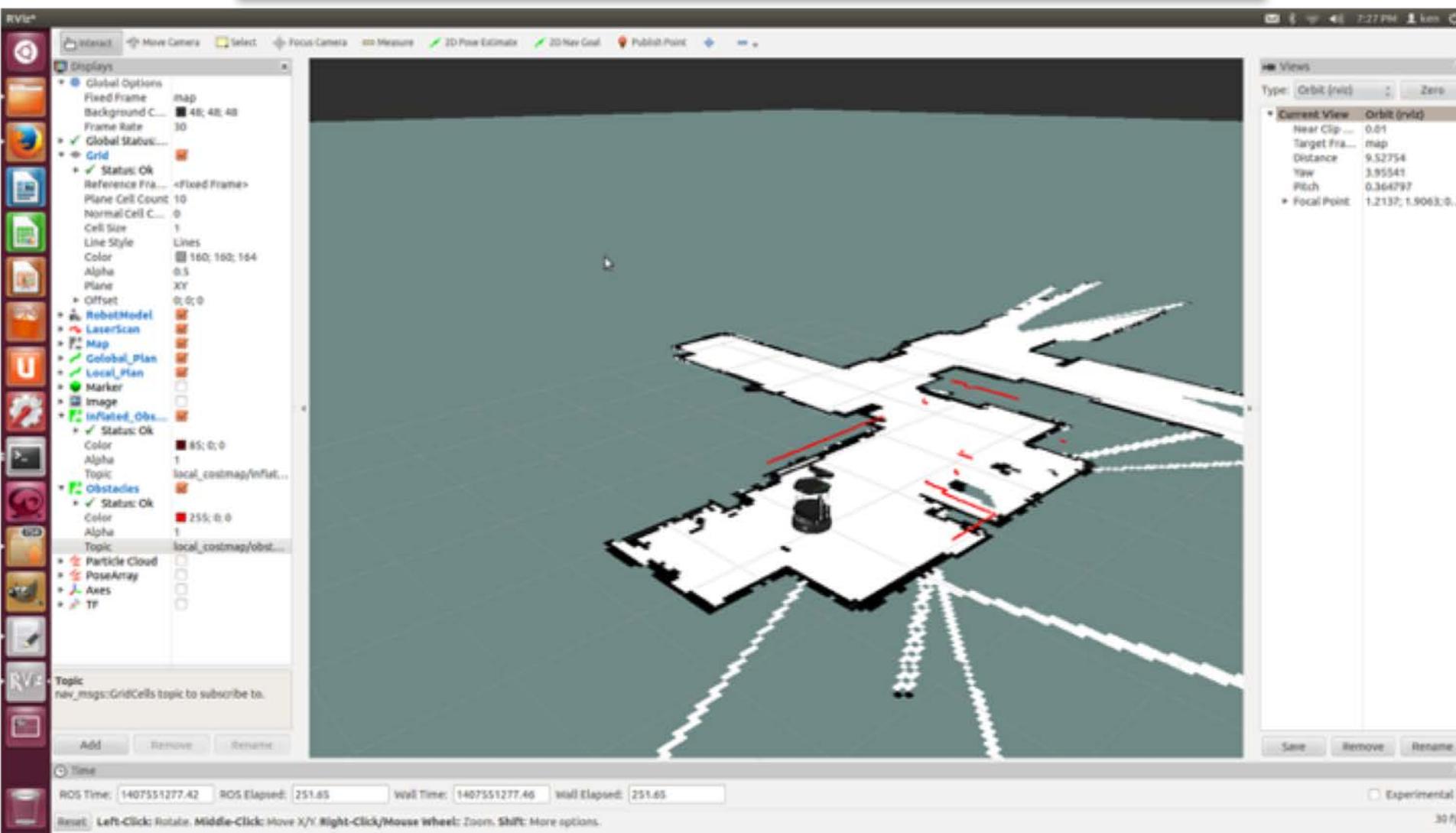
**More info**

<http://gazebosim.org/>

<http://gazebosim.org/tutorials>

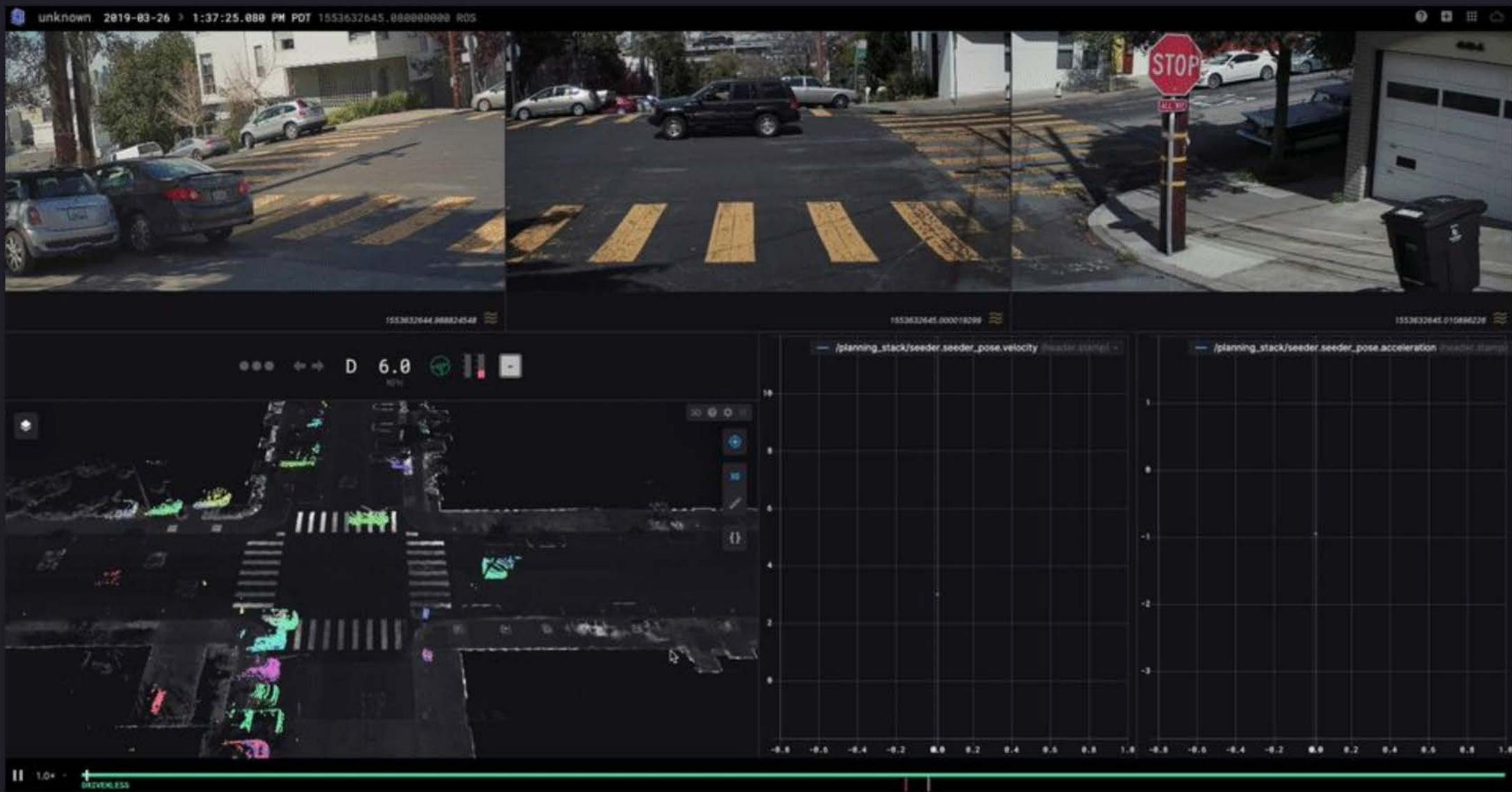
# 3D visualization tool: `rviz`

```
$ rosrun rviz rviz
```

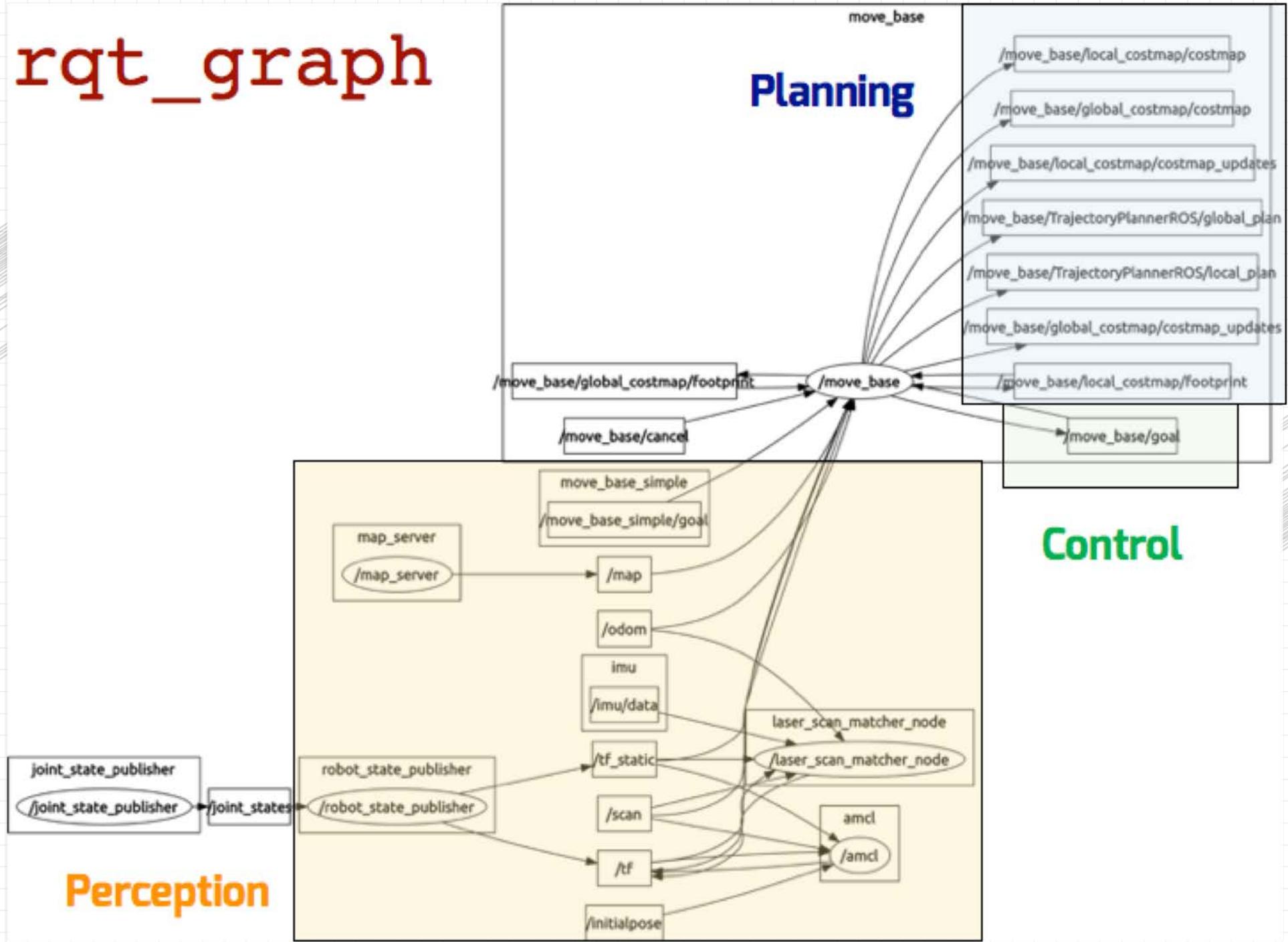


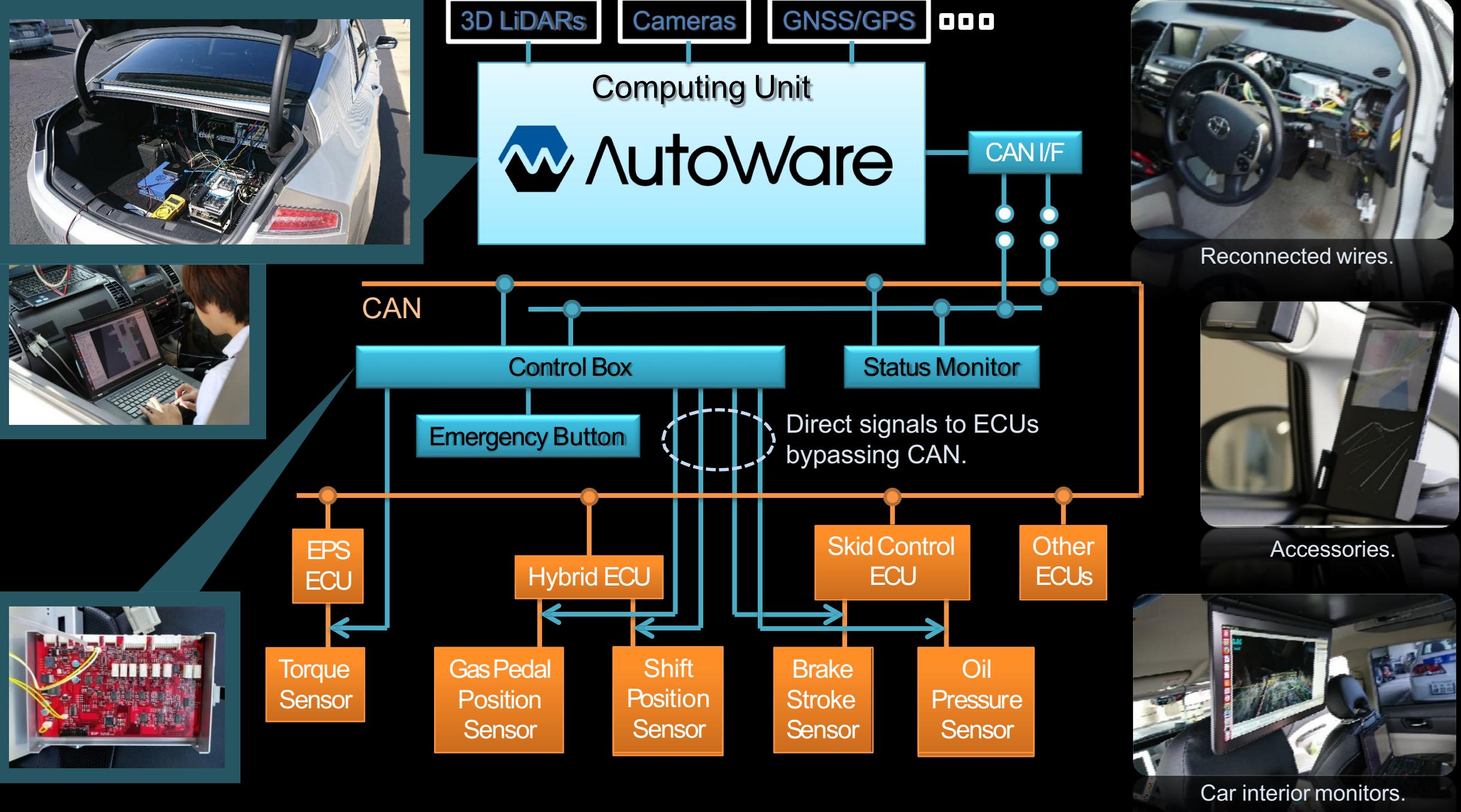


# Webviz



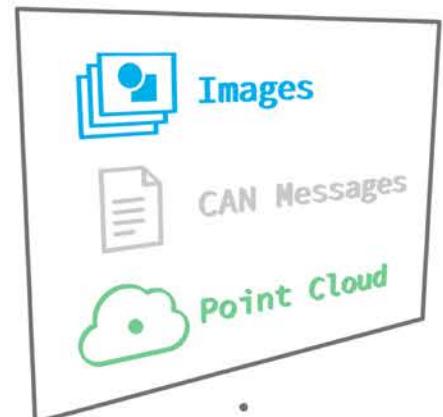
# rqt\_graph







ROSBAG Recording

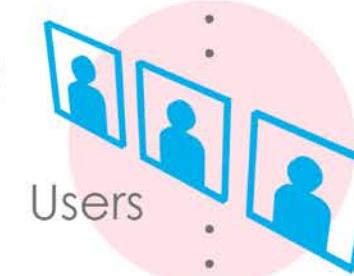


ROSBAG

Autoware Data



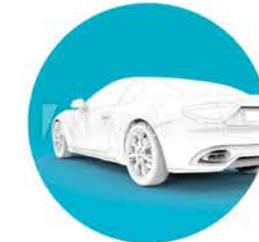
AI Research



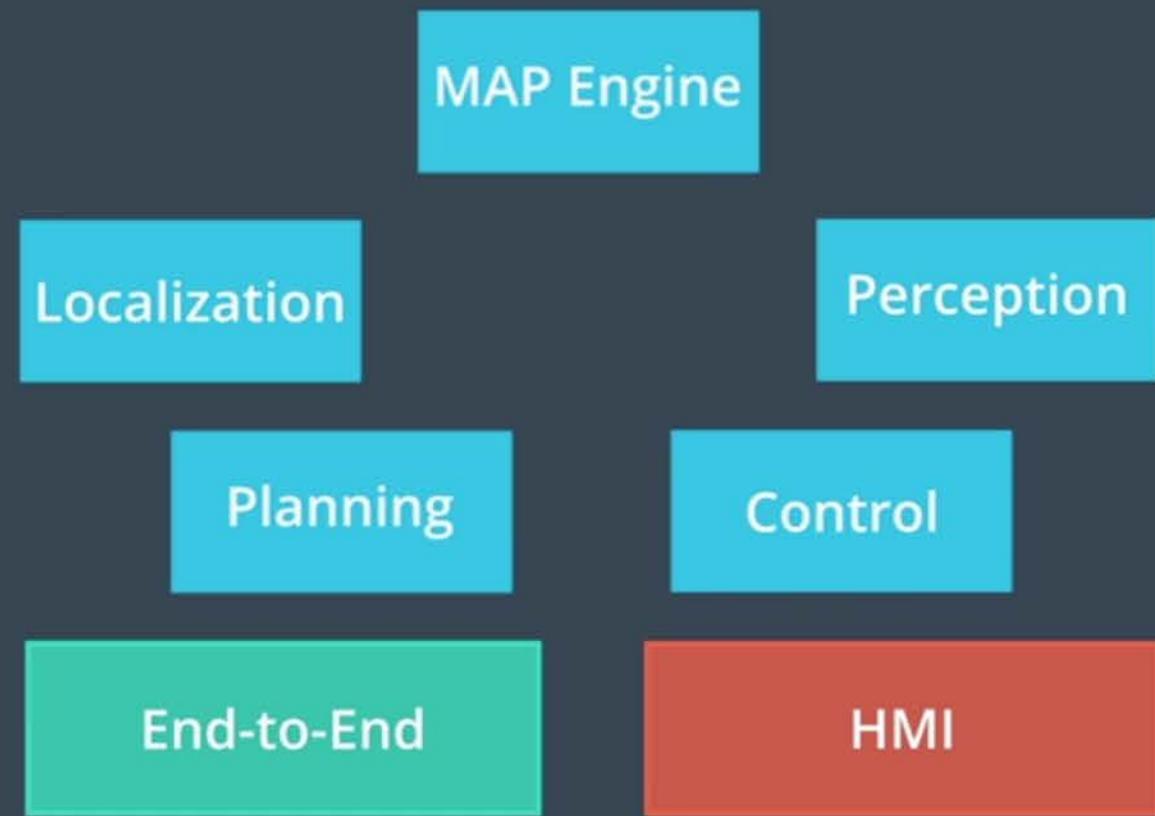
Users



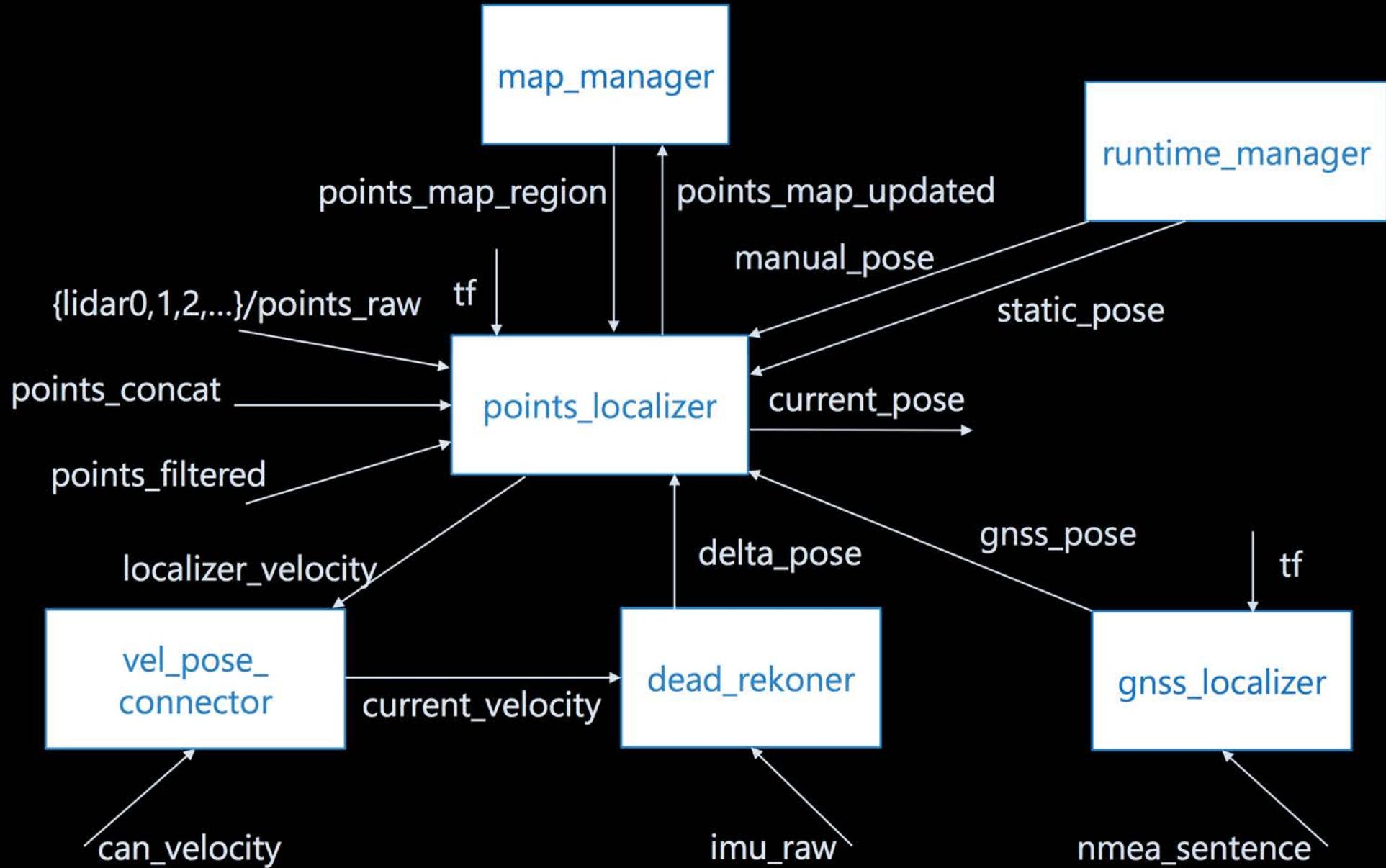
3D Mapping



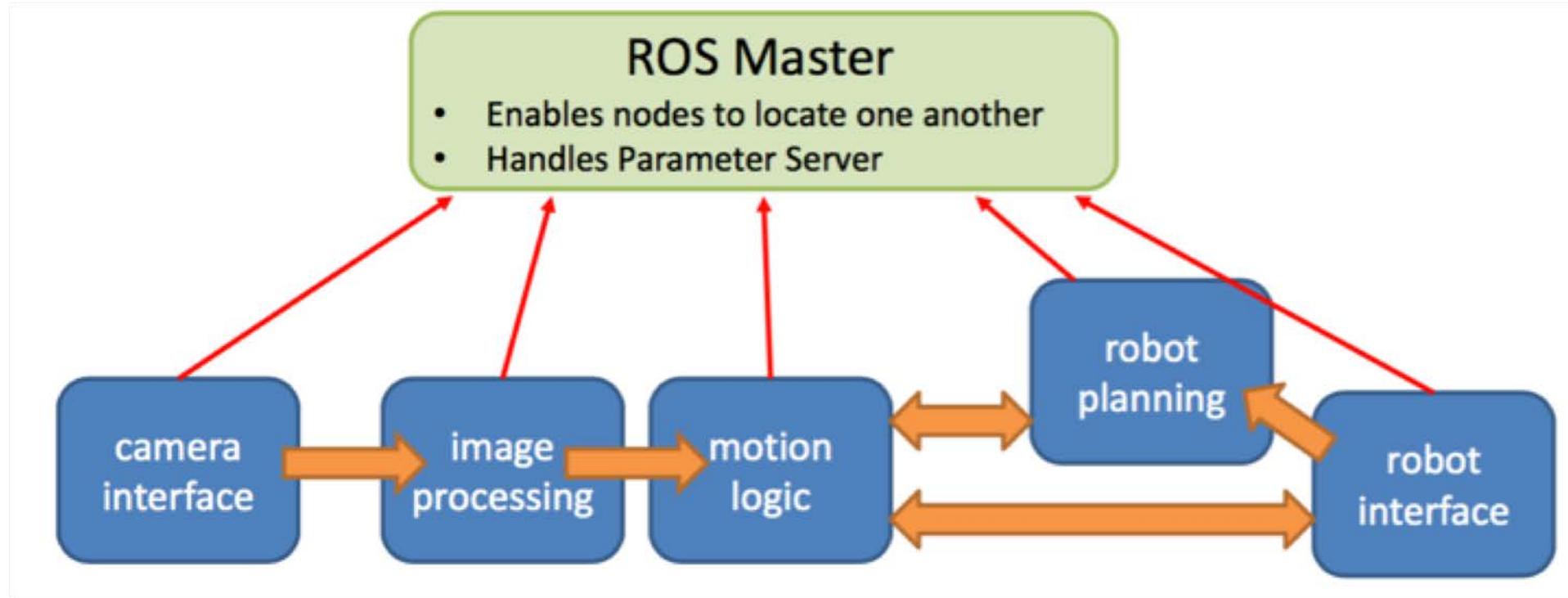
Simulation



# Packages Example (Localization)



# ROS: Nodes



**Node:** Program with a specific functionality, that runs as a single process.

Nodes communicate with other nodes using **topics** and **messages**

# ROS Master

- Manages the communication between nodes
- Every node registers at startup with the master

ROS Master

Start a master with

```
> roscore
```

More info

<http://wiki.ros.org/Master>

# ROS Nodes

- Single-purpose, executable program
- Individually compiled, executed, and managed
- Organized in *packages*

Run a node with

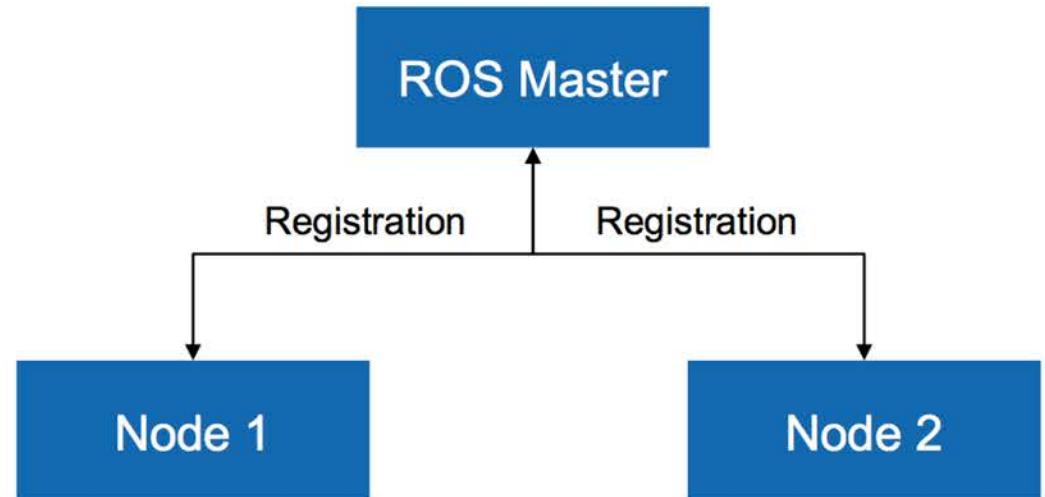
```
> rosrun package_name node_name
```

See active nodes with

```
> rosnodes list
```

Retrieve information about a node with

```
> rosnodes info node_name
```



More info

<http://wiki.ros.org/rosnodes>

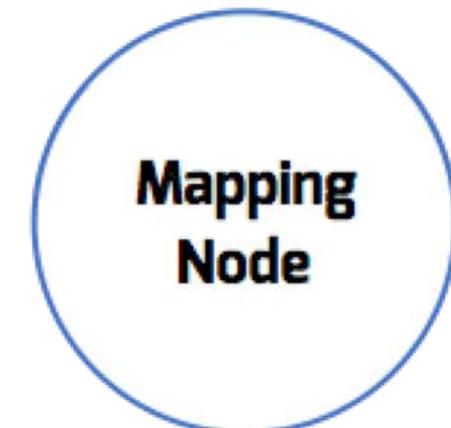
# ROS: Topics

**Topics** are channels over which nodes exchange messages.

They are for **streaming data**



**hokuyo\_node**



Subscribes to topic: Scan

Publisher Node

Subscriber Node

# ROS Topics

- Nodes communicate over *topics*
  - Nodes can *publish* or *subscribe* to a topic
  - Typically, 1 publisher and  $n$  subscribers
- Topic is a name for a stream of *messages*

List active topics with

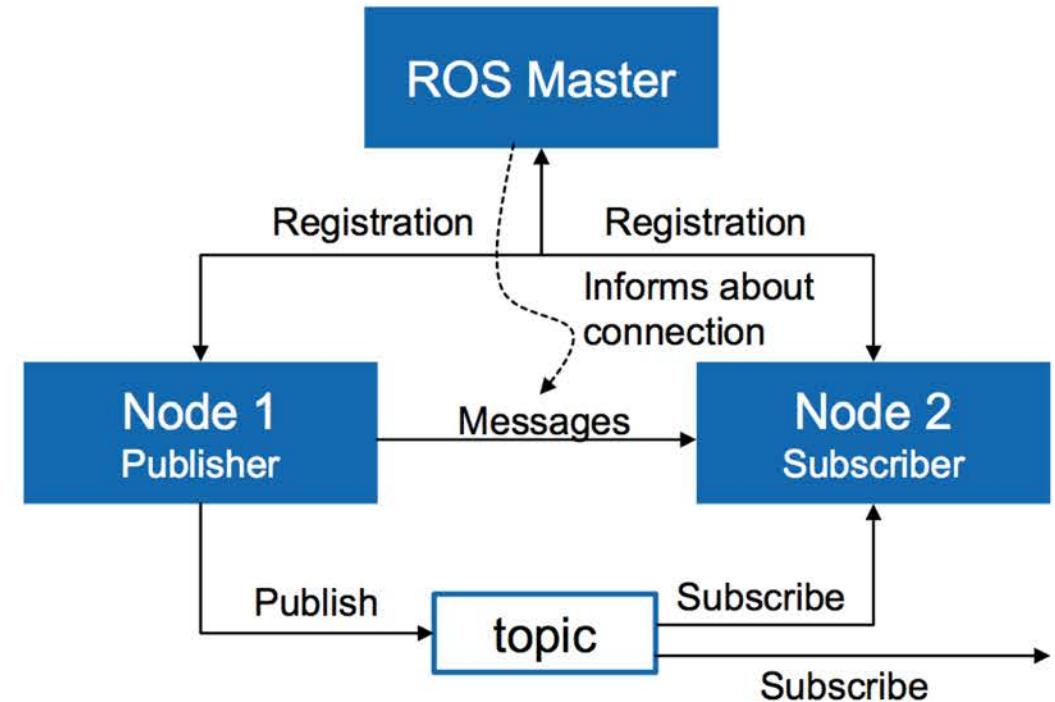
```
> rostopic list
```

Subscribe and print the contents of a topic with

```
> rostopic echo /topic
```

Show information about a topic with

```
> rostopic info /topic
```



More info

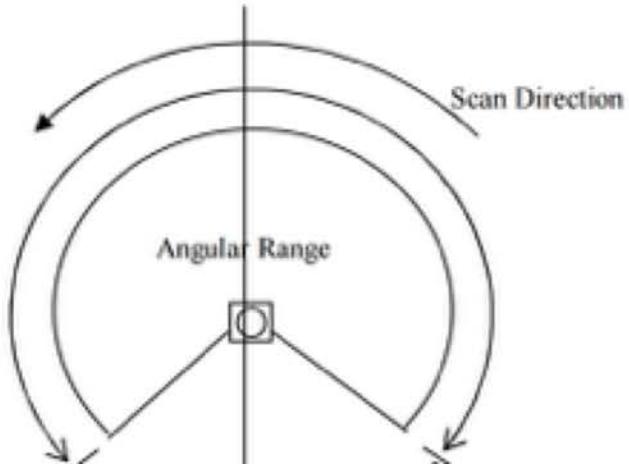
<http://wiki.ros.org/rostopic>

# ROS: Messages

**Messages** are the strongly-typed **data structure** for a topic.



**hokuyo\_node**



LaserScan [Message]

Scan [Topic]



**Mapping  
Node**

`std_msgs/Header` header  
`float32 angle_min`  
`float32 angle_max`  
`float32 angle_increment`  
`float32 time_increment`  
`float32 scan_time`  
`float32 range_min`  
`float32 range_max`  
`float32[] ranges`  
`float32[] intensities`

**Subscriber Node**

# ROS Messages

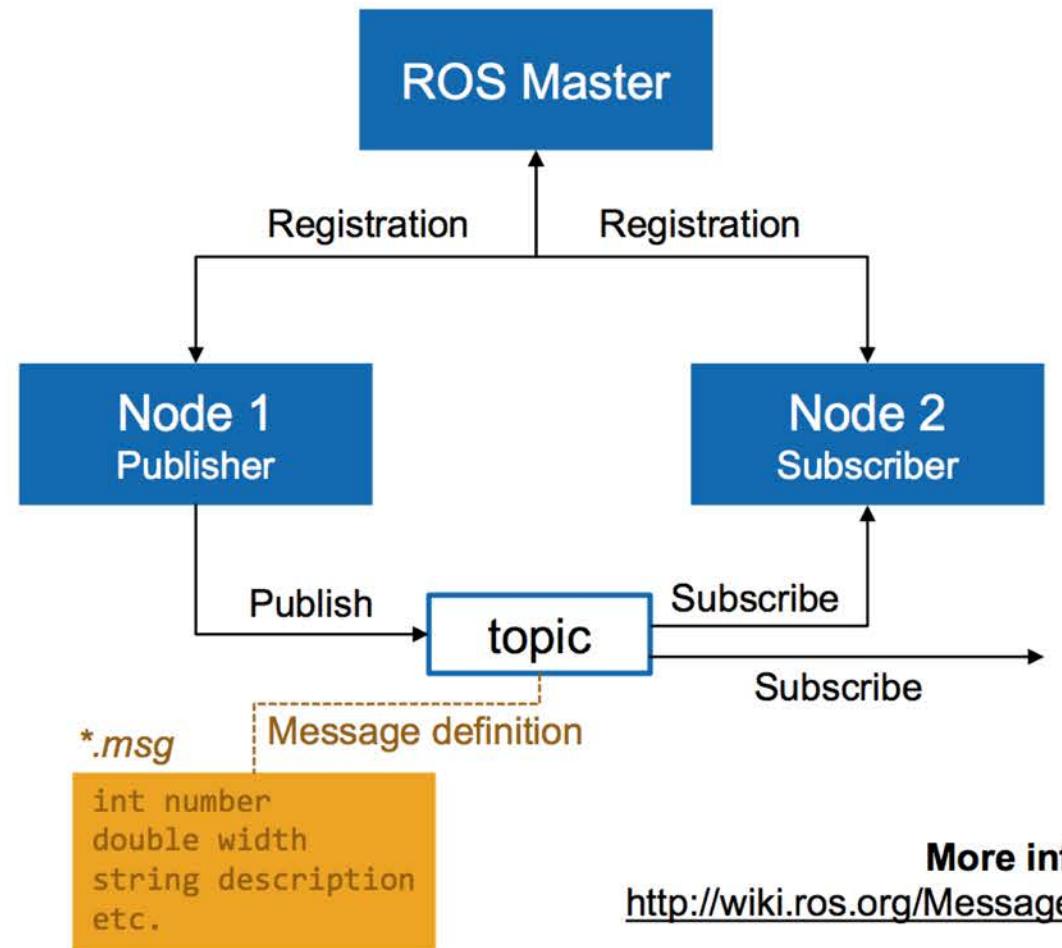
- Data structure defining the *type* of a topic
- Comprised of a nested structure of integers, floats, booleans, strings etc. and arrays of objects
- Defined in *\*.msg* files

See the type of a topic

```
> rostopic type /topic
```

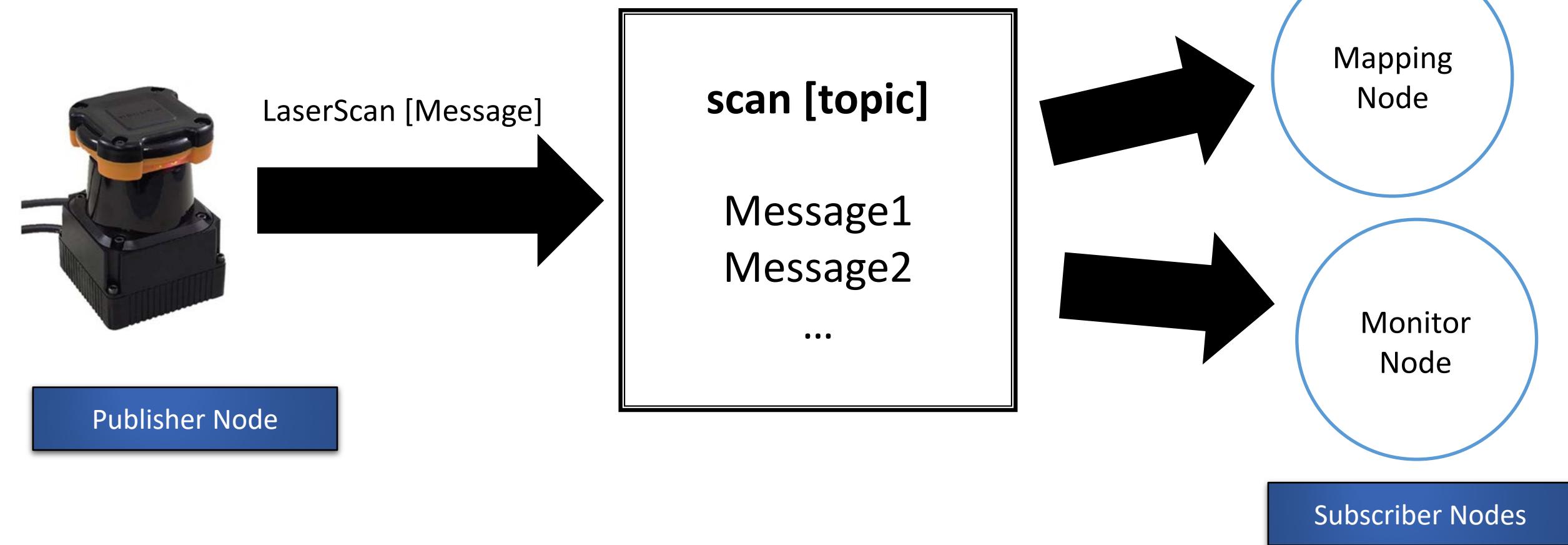
Publish a message to a topic

```
> rostopic pub /topic type args
```



# Communication between nodes

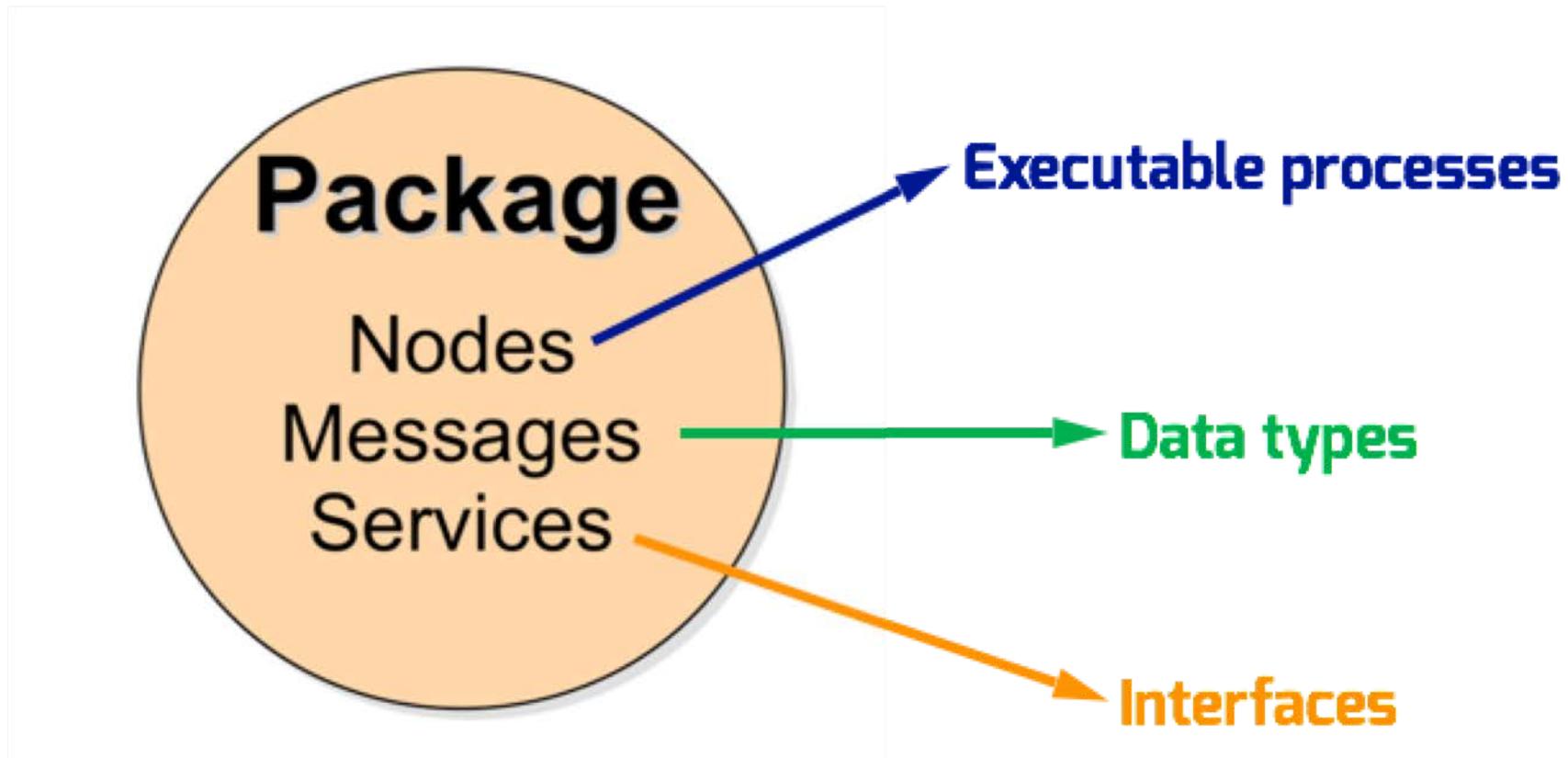
Nodes communicate **messages** via **topics**  
in an asynchronous publish-subscribe model



# ROS: Packages

Software in ROS is organized into **packages**.

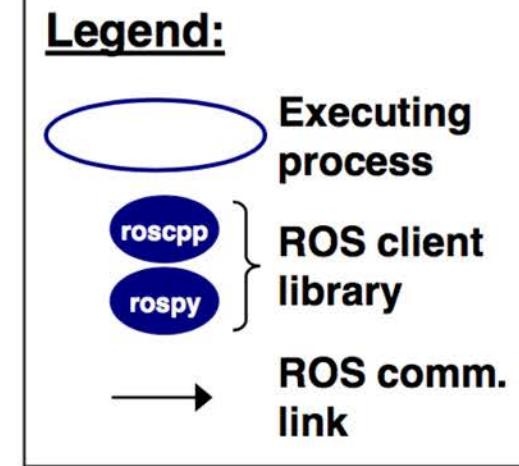
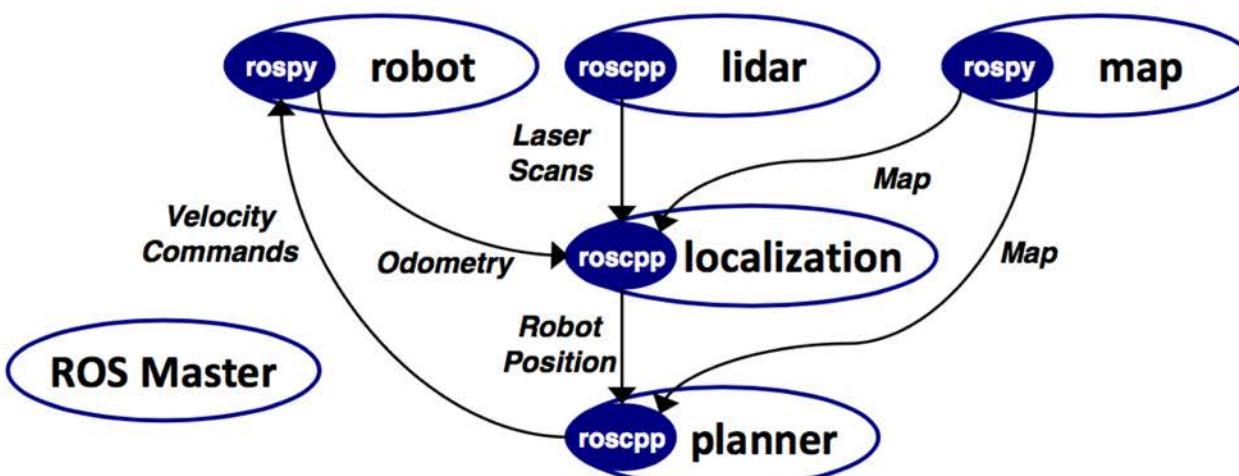
A **package** contains one or more **nodes**.



# ROS Computational Graph / Communication: Computational Graph

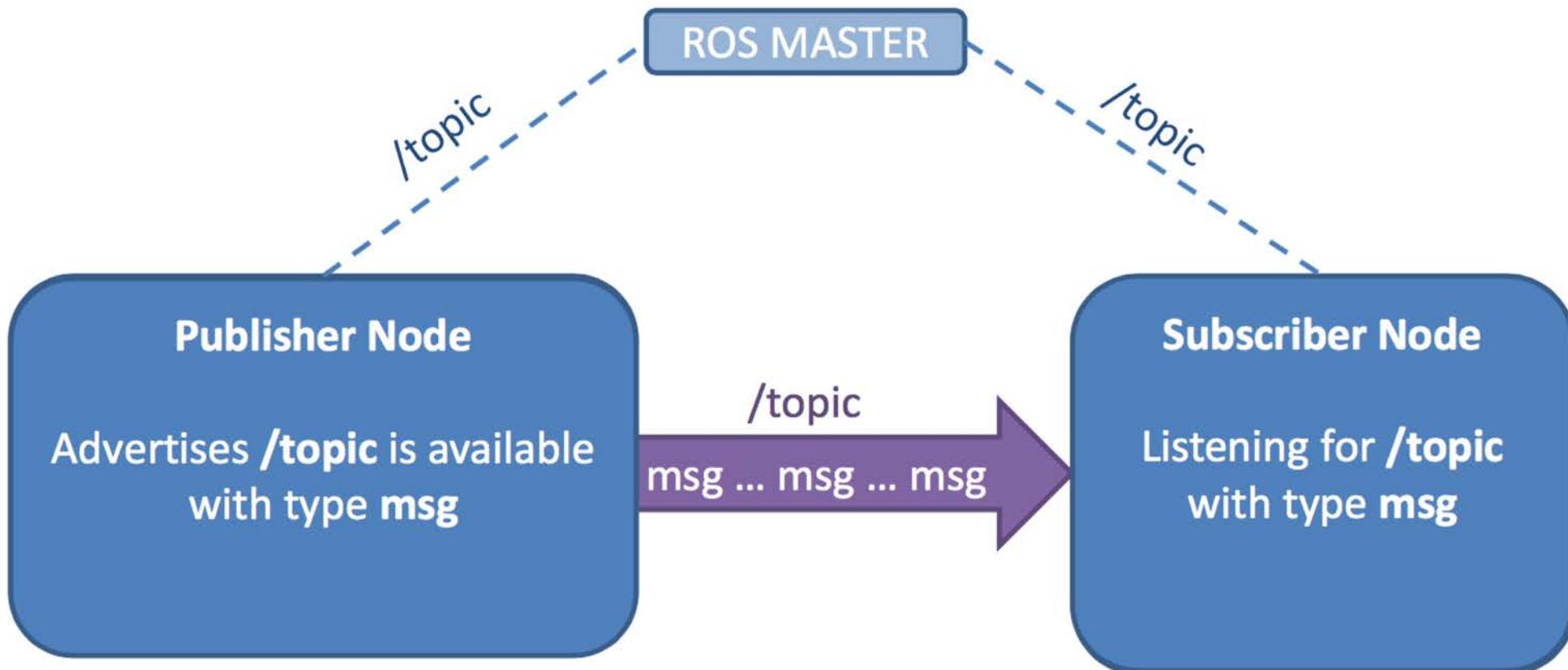
- ROS employs a modular, peer-to-peer design pattern
  - Independent processes performing specific tasks
    - Read data from a sensor, compute a localization algorithm, plan a path to a goal, etc.
  - Processes communicate with each other using well-defined messages
    - Laser scans, robot position, velocity commands, occupancy grid map, etc.
- The network of processes form the “ROS computational graph”
- A typical robot application may consist of a few to 100+ ROS processes
  - Often a mix of developer’s own and others’ processes

An example robot application (known-map navigation):



# ROS Topics/Messages

Topics are for **Streaming Data**



- Each **Topic** is a stream of **Messages**:
  - sent by **publisher(s)**, received by **subscriber(s)**
- Messages are **asynchronous**
  - publishers don't know if anyone's listening
  - messages may be dropped
  - subscribers are event-triggered (by incoming messages)
- Typical Uses:
  - Sensor Readings: camera images, distance, I/O
  - Feedback: robot status/position
  - Open-Loop Commands: desired position

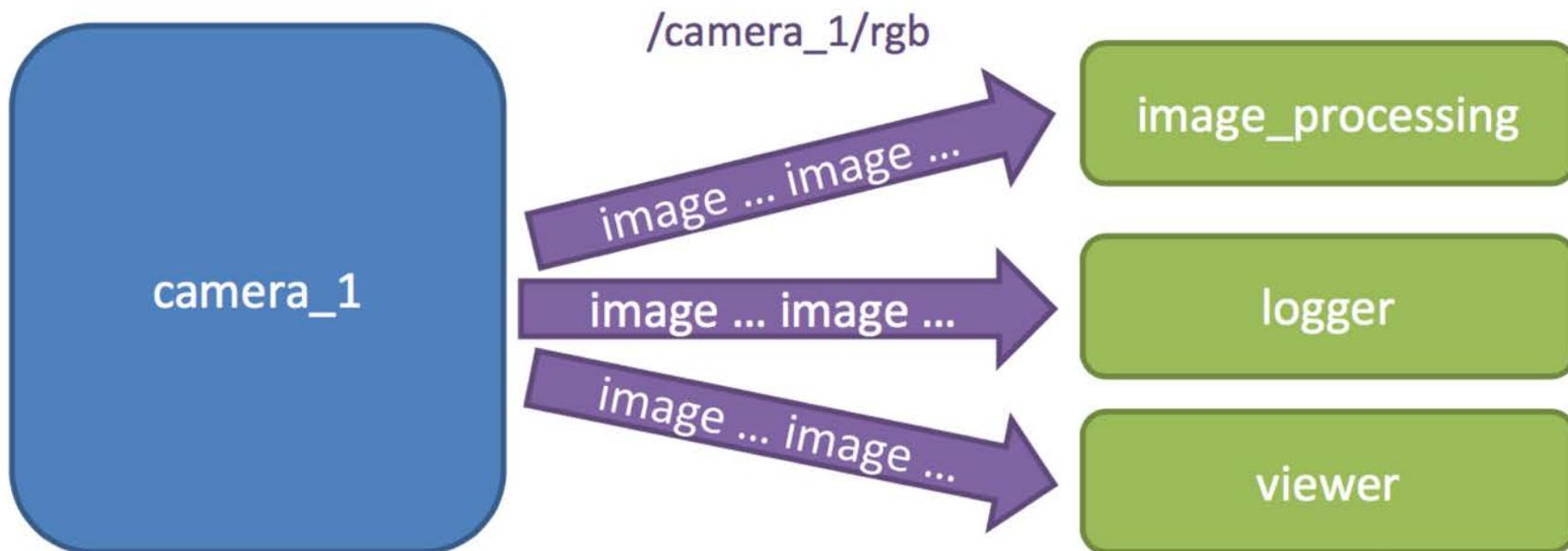
# Topics vs. Messages

- Topics are **channels**, Messages are **data types**
  - Different topics can use the same Message type



# Multiple Pub/Sub

- Many nodes can pub/sub to same topic
  - comms are direct node-to-node

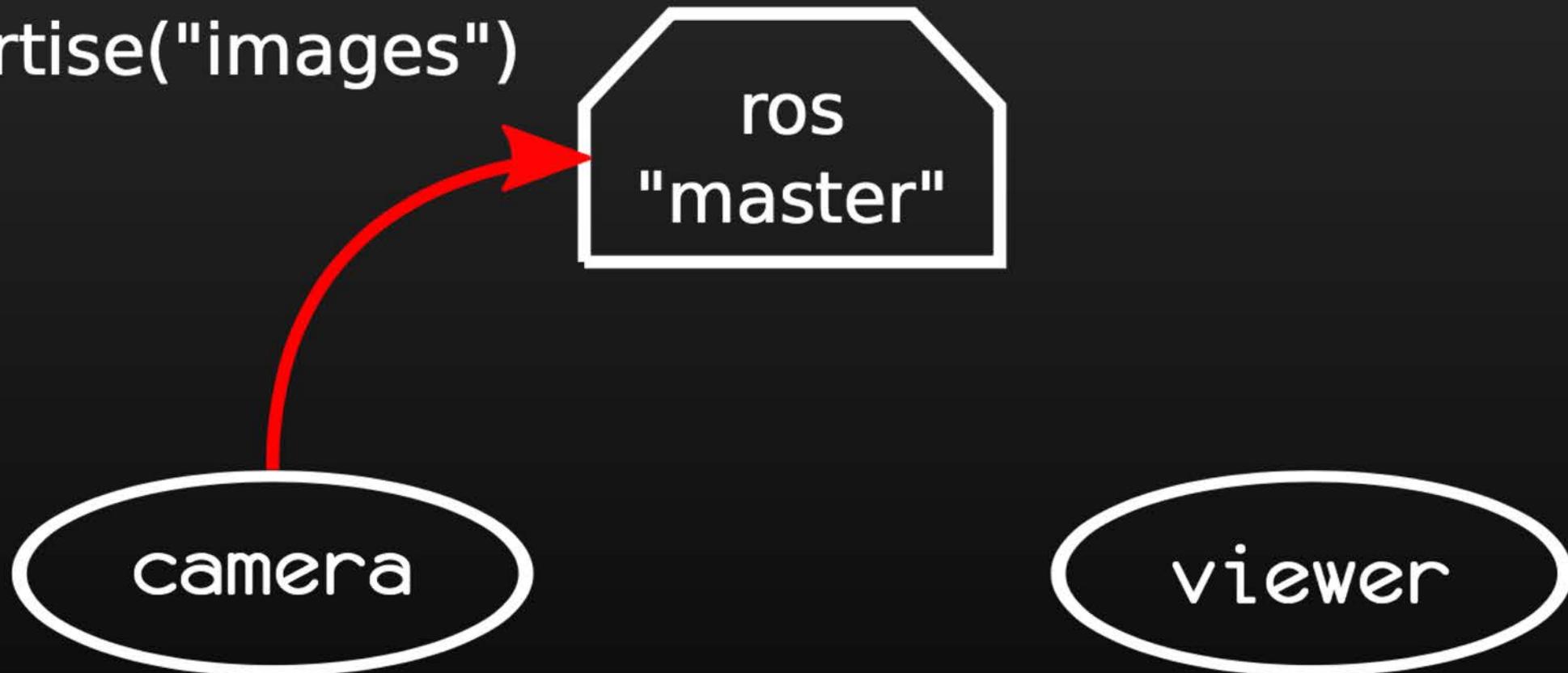


ros  
"master"

camera

viewer

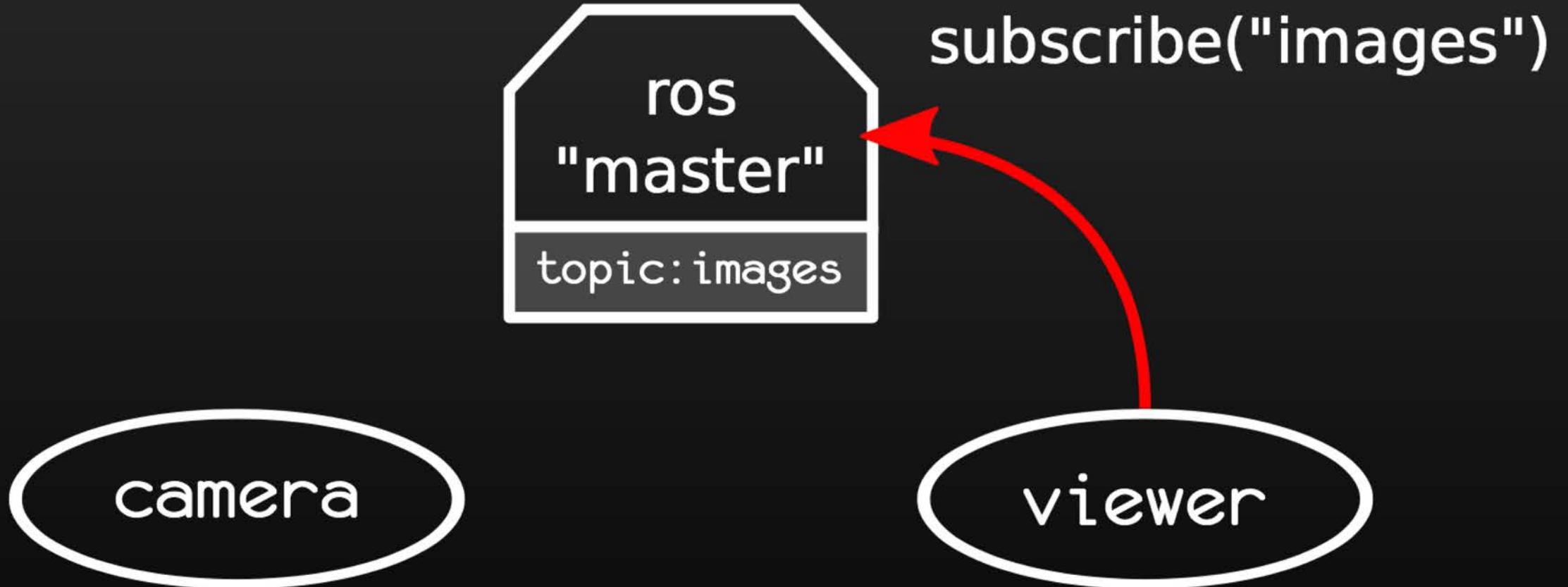
```
advertise("images")
```

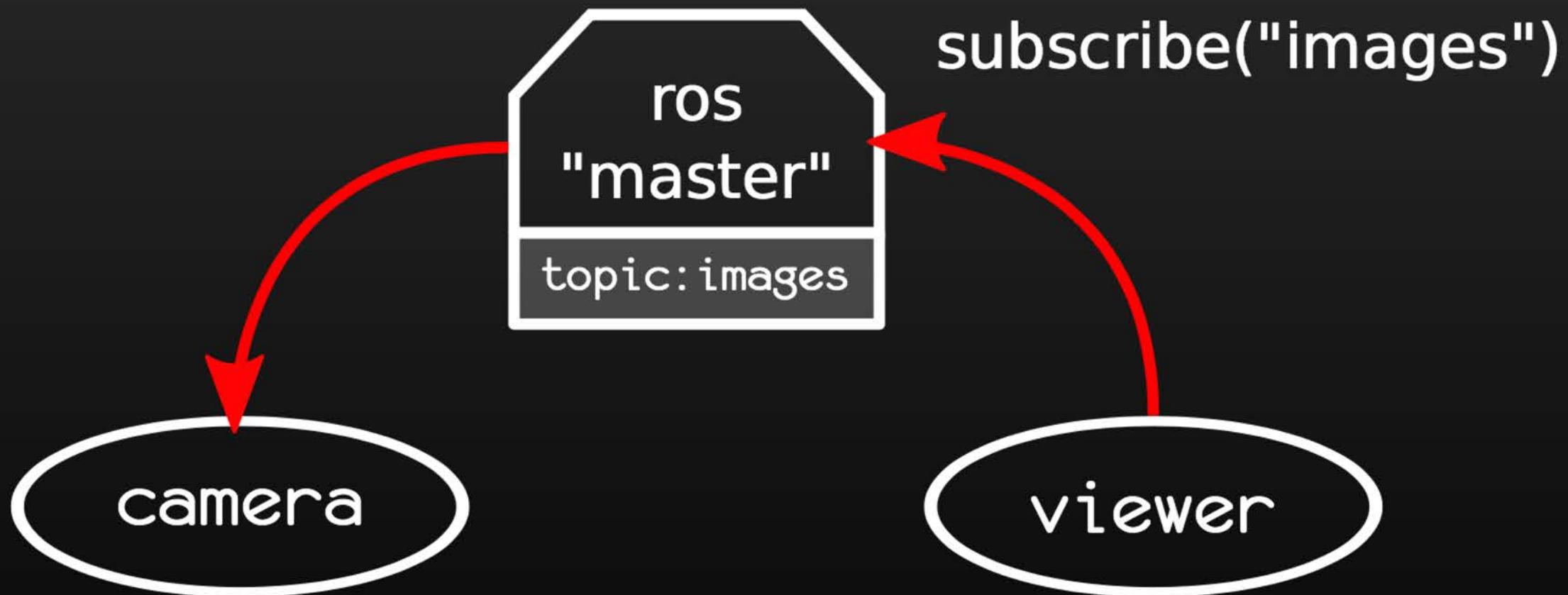




camera

viewer









camera

viewer

publish(img)



images (tcp)

camera

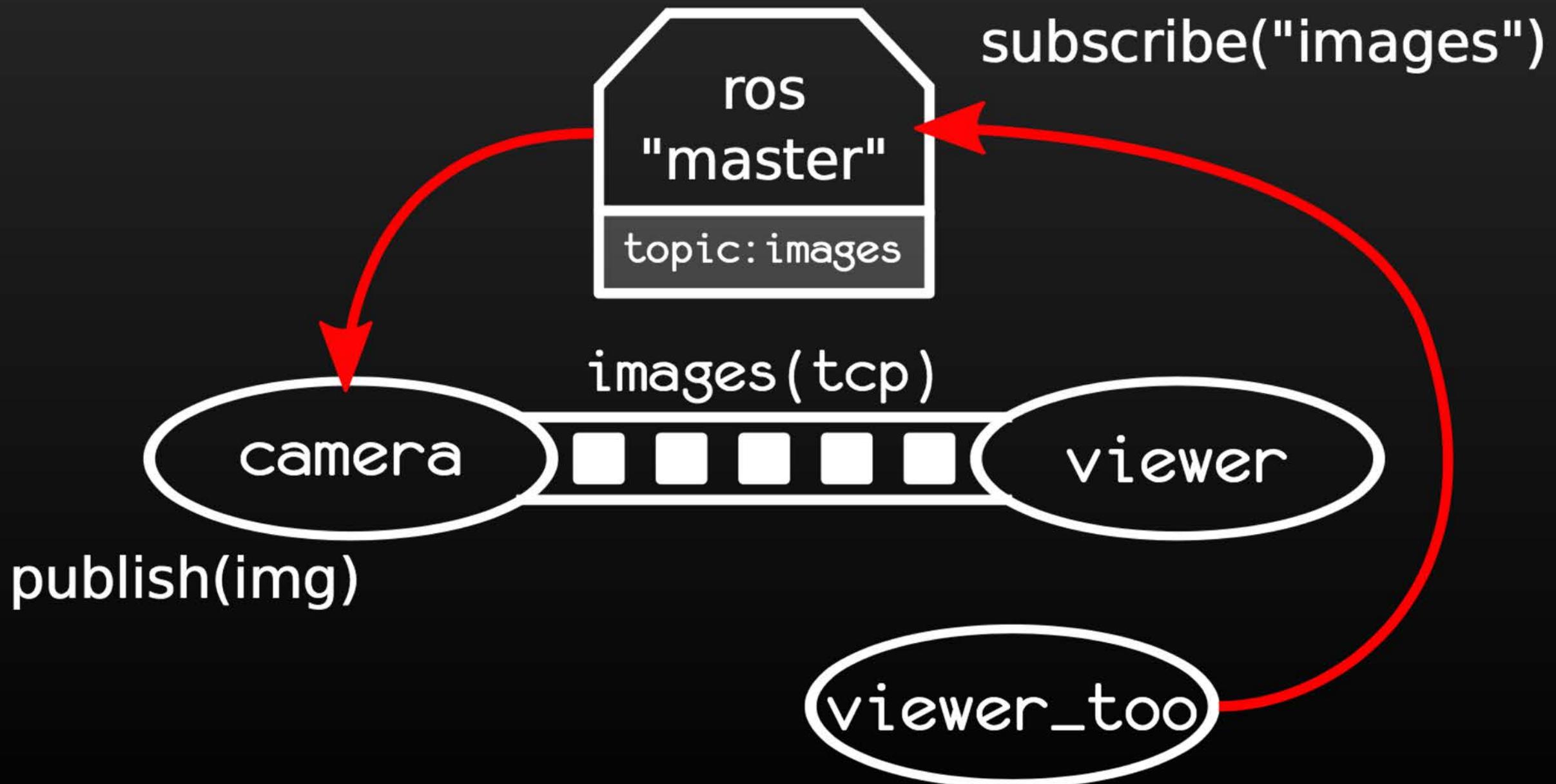
viewer

publish(img)



publish(img)







images (tcp)



# Basic ROS commands: **roscore**

**roscore** is the first thing that you should run when starting ROS.

```
$ roscore
```

Collection of nodes and programs that are pre-requisites of a ROS-based system.

It starts up:

- The ROS Master
- A rosout logging node.

# Basic ROS commands: **rosrun**

**rosrun** executes a ROS node.

```
$ rosrun <package_name> <node_name>
```

Example

```
$ rosrun hokuyo_node hokuyo_node
```



hokuyo\_node

# Basic ROS commands: `rosnode`

Command	Description
<code>rosnode list</code>	List all active nodes
<code>rosnode info node_name</code>	Display information about a node
<code>rosnode kill node_name</code>	Kill running node
<code>Rosnode ping node_name</code>	Test connectivity to an active node

# Basic ROS commands: `rostopic`

Command	Description
<code>rostopic list</code>	List all topics currently subscribed to and/or publishing
<code>rostopic info &lt;topic&gt;</code>	Show topic message type, subscribers, publishers etc.
<code>rostopic echo &lt;topic&gt;</code>	Echo messages published to the topic on the terminal window
<code>rostopic find &lt;message_type&gt;</code>	Find topics of the given message type

# ROS Client Libraries

Client Library	Language	Comments
<code>roscpp</code>	C++	<b>Most widely used, high performance</b>
<code>rospy</code>	Python	<b>Good for rapid-prototyping and non-critical-path code</b>
<code>roslisp</code>	LISP	<b>Used for planning libraries</b>
<code>rosjava</code>	Java	<b>Android support</b>
<code>roslua</code>	Lua	<b>Light-weight scripting</b>
<code>roscs</code>	Mono/.Net	<b>Any Mono/.Net language</b>
<code>roseus</code>	EusLisp	
<code>PhaROS</code>	Pharo Smalltalk	
<code>rosR</code>	R	<b>Statistical programming</b>

**Experimental**

# Client API Commonly Used Features

Object / Feature	Description	roscpp	rospy
API root	Objects and methods for interacting with ROS	ros::NodeHandle	rospy
Parameter server client	Query and set parameter server dictionary entries	.getParam .param .searchParam .setParam	.get_param .search_param .set_param
Subscriber	Receive messages from a topic	.subscribe	.Subscriber
Publisher	Send messages to a topic	.advertise	.Publisher
Service	Serve and call remote procedures	.advertiseService .serviceClient	.Service .ServiceProxy
Timer	Periodic interrupt	.createTimer	.Timer
Logging	Output strings to rosconsole	ROS_DEBUG, ROS_INFO, ROS_WARN, etc.	.logdebug, .loginfo, .logwarn, .logerr, .logfatal
Initialization & Event Loop	Set node name, contact Master, enter main event loop	ros::init .spin	.init_node .spin
Messages	Create and extract data from ROS messages	Specifics depends on message	
		std_msgs::String	std_msgs.msg.String