

# F1/10 Autonomous Racing

Introduction  
To ROS

Madhur Behl

CS 4501/SYS 4582  
Spring 2019  
Rice Hall 120

Acknowledgements

AutoWare  
Open Robotics ROSCON

# Announcements

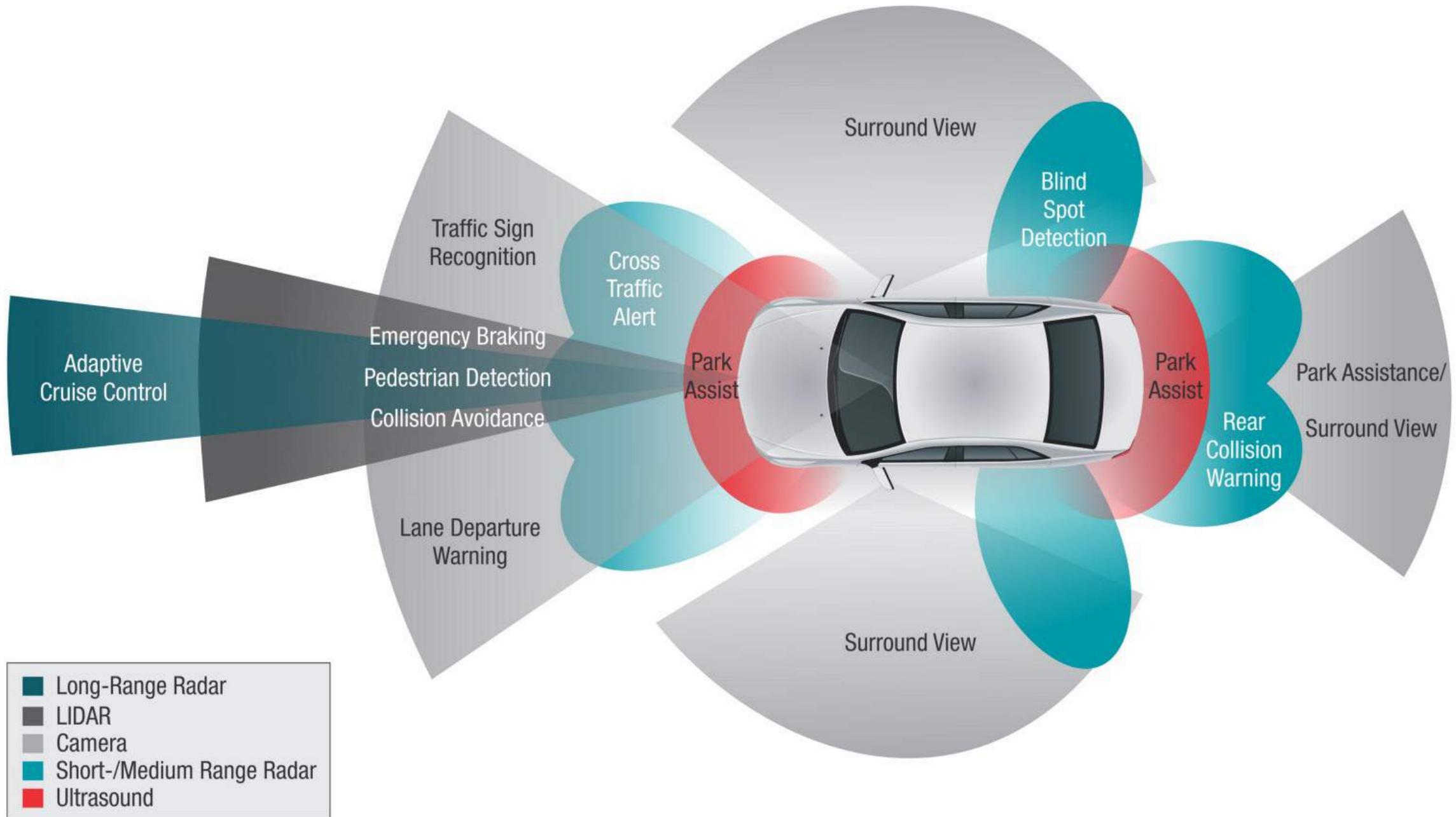
- VM and ROS installation instructions posted on Webpage/Piazza.
- Install VM on your laptop.
  - Install Ubuntu on VM or dual boot your laptop with an Ubuntu install.
  - **Tutorial0-a**
  - **16.04** or 14.04
- Install ROS on Ubuntu and bring it for the lab session on Wednesday.
  - **Tutorial0-b**
  - **ROS Kinetic Kame** or Indigo Igloo



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

# Today's lecture

- A gentle introduction to ROS.







# Sensor Integration



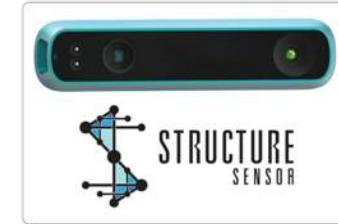
**LiDAR**



**Camera**



**IMU**



**IR Depth Cameras**



**Wi-fi Telemetry**



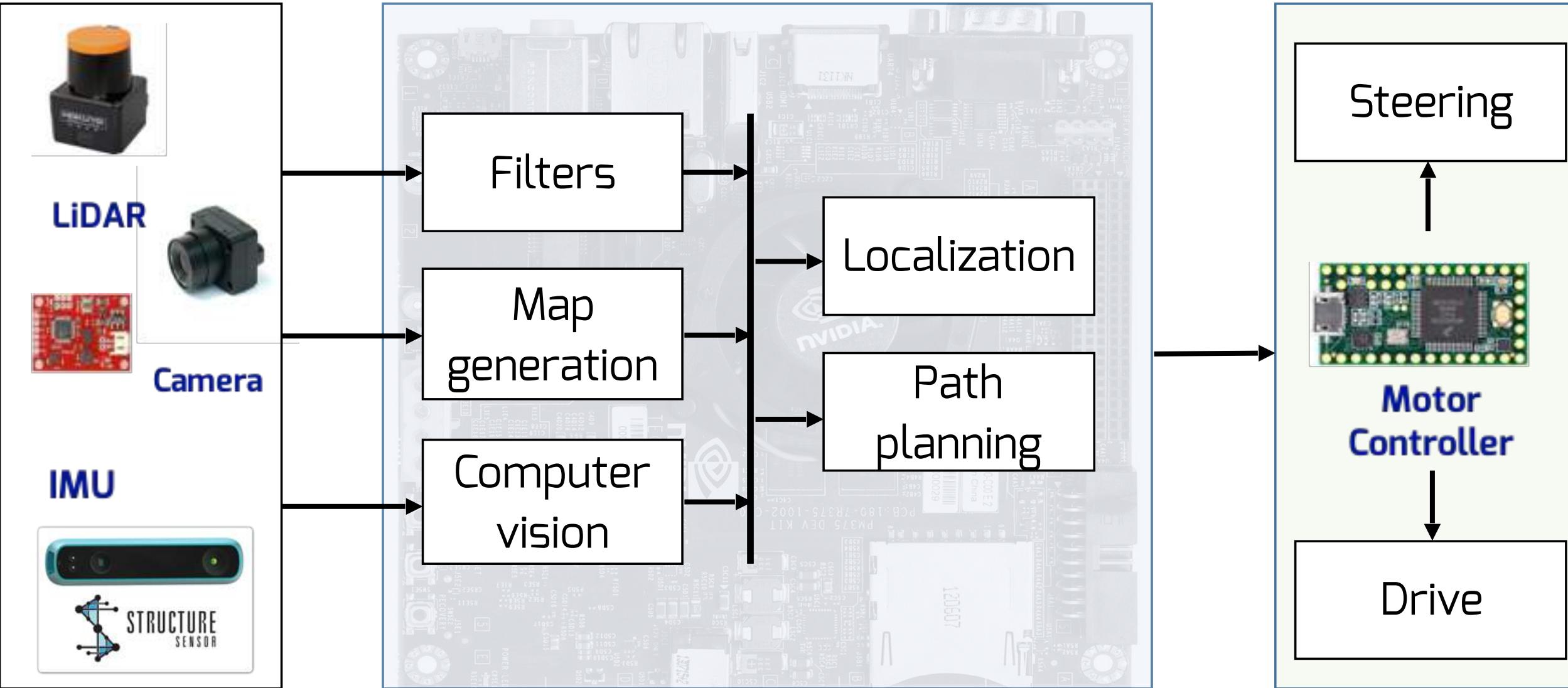
**Onboard Computer**



**Motor  
Controller**



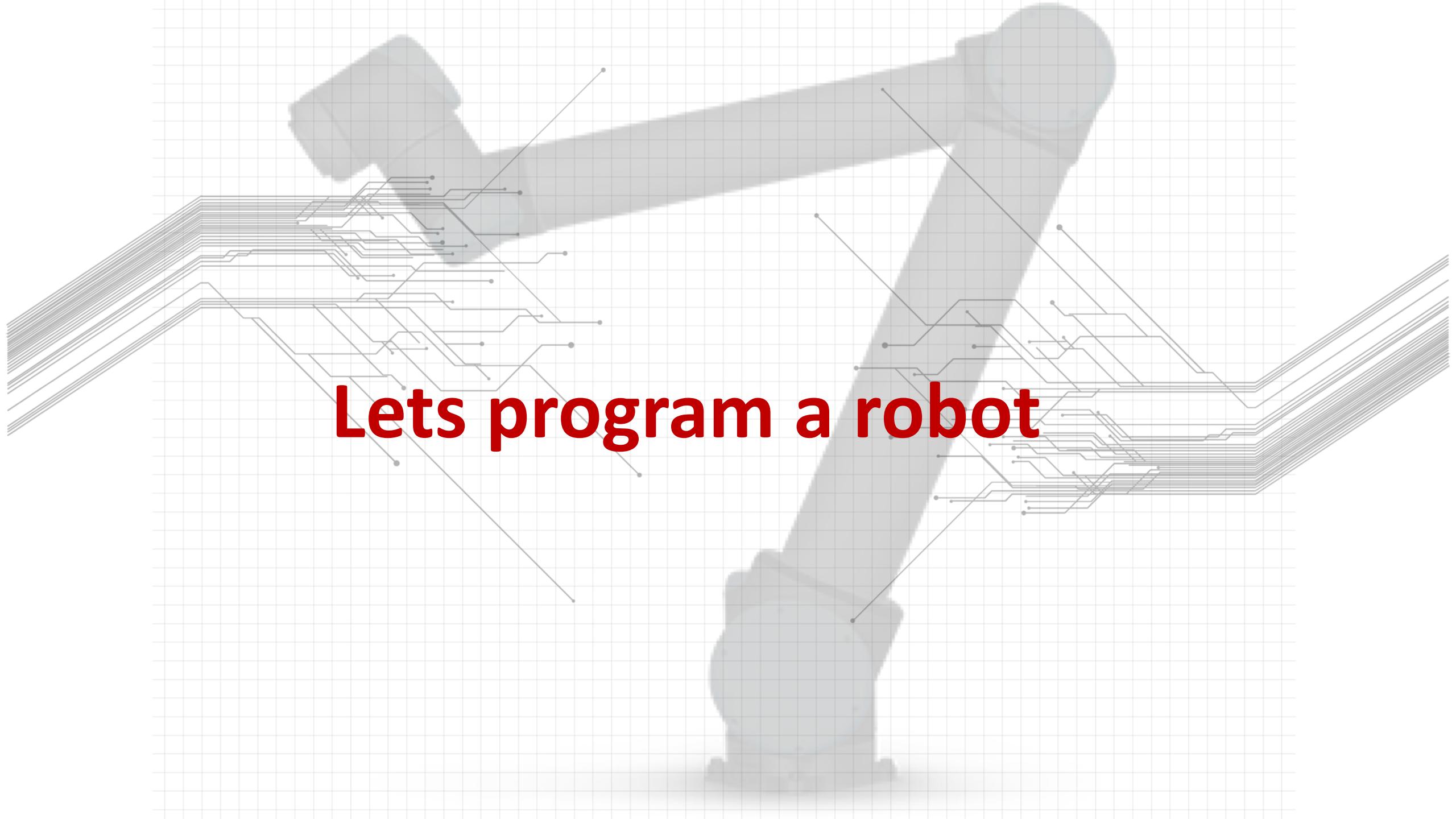
**Battery**



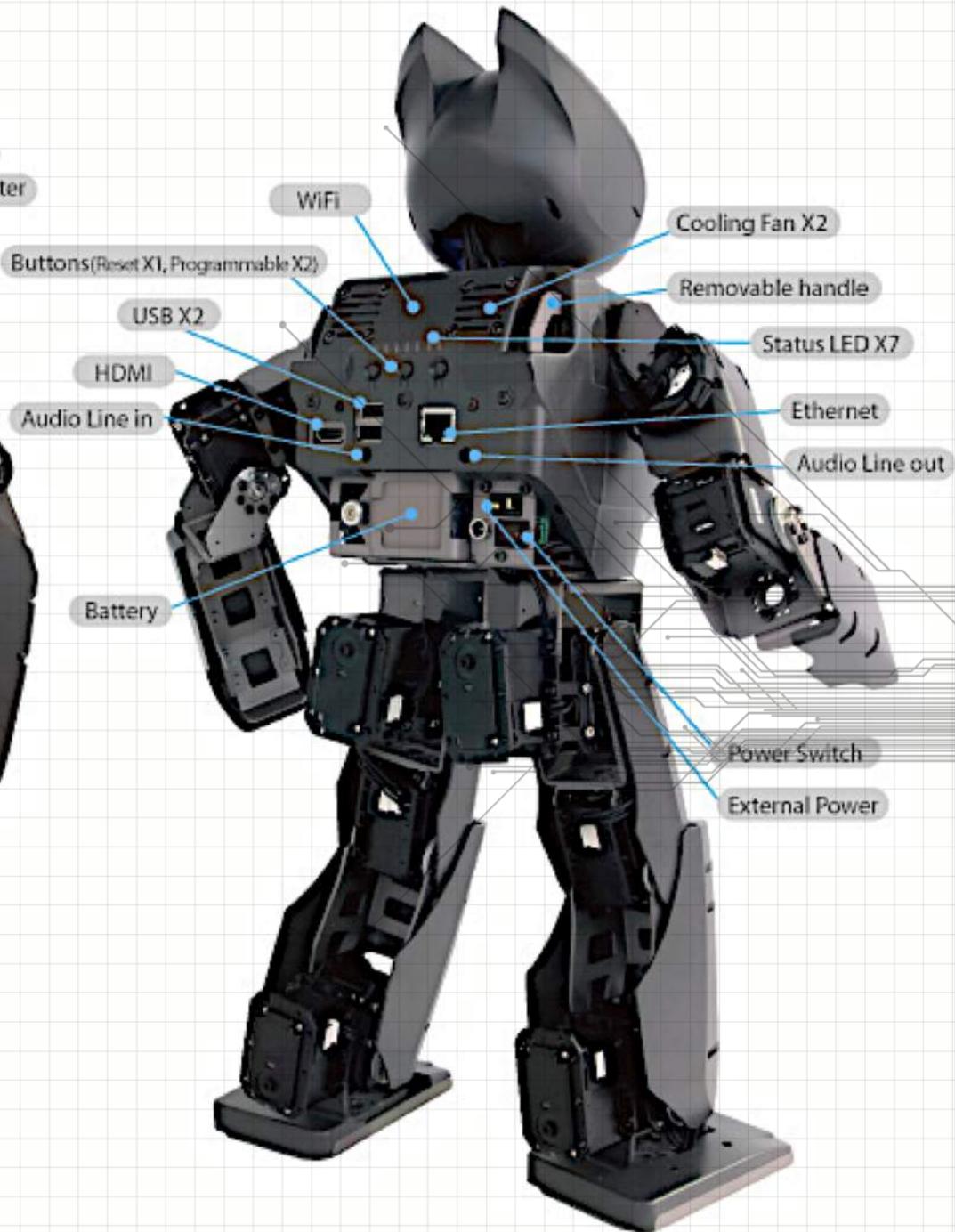
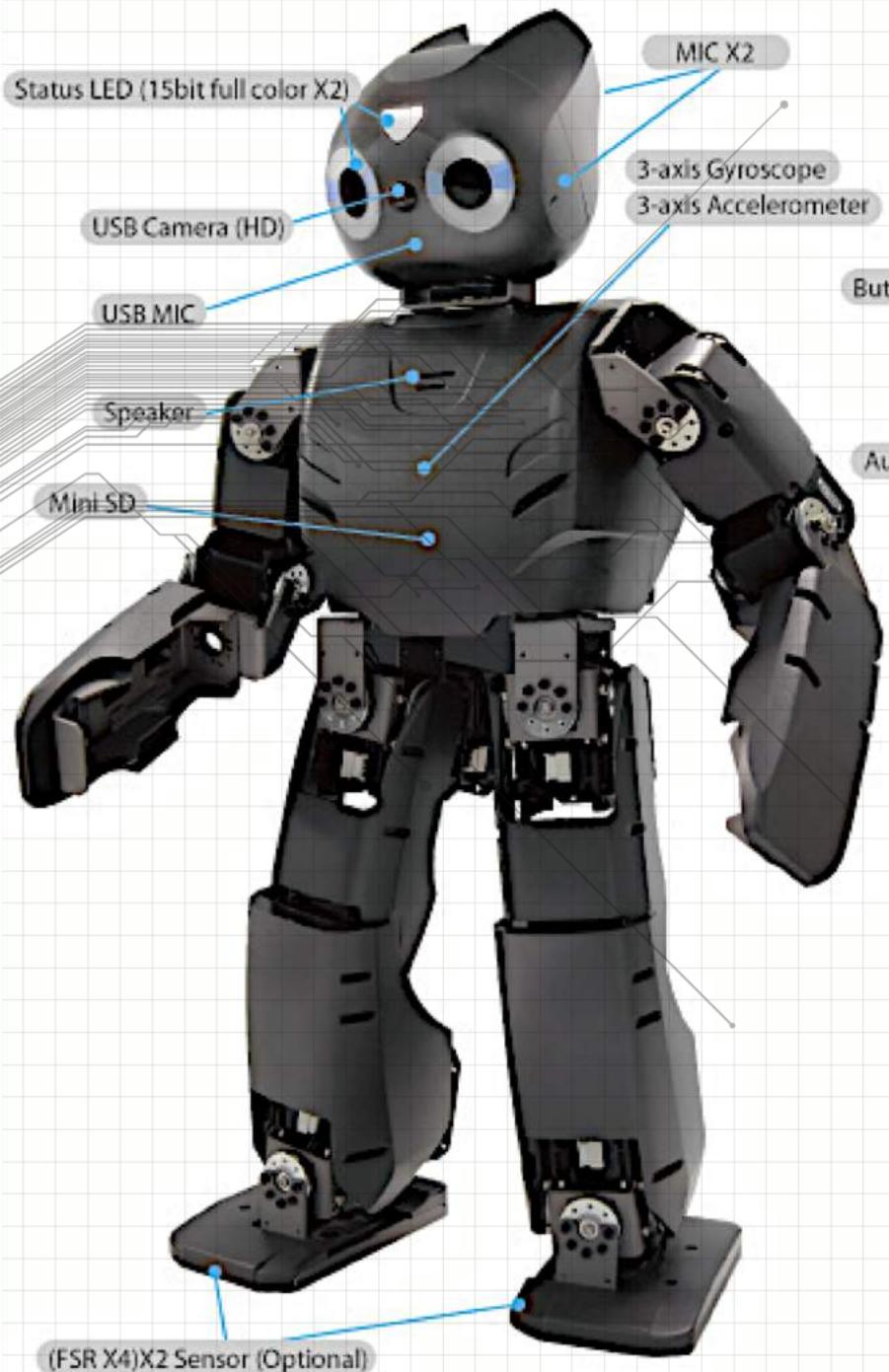
Perception

Planning

Control



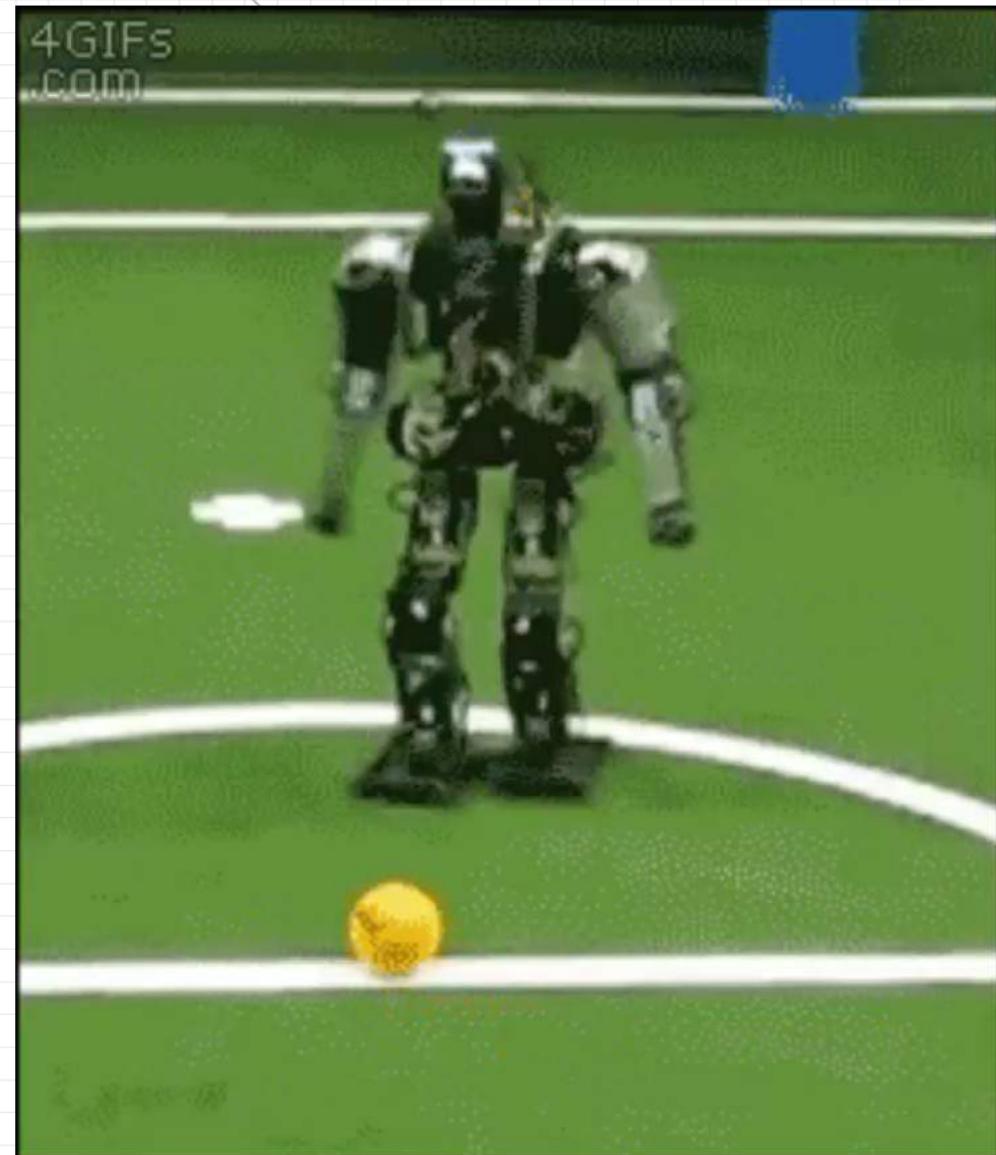
# Lets program a robot





## 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\*

---

- **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

\*We are making a distinction between robotics software development (i.e. software engineering) and robotics algorithms (i.e. computer or autonomy science). We'll cover the challenges of robotics algorithms later this week.



**What a mess!**

How can we deal with it ?

# ROS: Robot Operating System



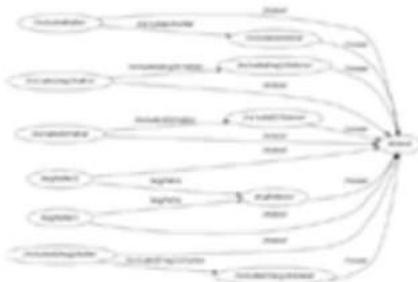
About Why ROS? Getting Started Get Involved Blog

## What is ROS?

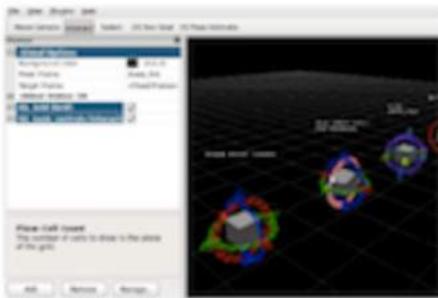
The Robot Operating System (ROS) is a set of software libraries and tools that help you build robot applications. From drivers to state-of-the-art algorithms, and with powerful developer tools, ROS has what you need for your next robotics project. And it's all open source.

[Read More](#)





+



+



+



ros.org

## Plumbing

- Process management
- Inter-process communication
- Device drivers

## Tools

- Simulation
- Visualization
- Graphical user interface
- Data logging

## Capabilities

- Control
- Planning
- Perception
- Mapping
- Manipulation

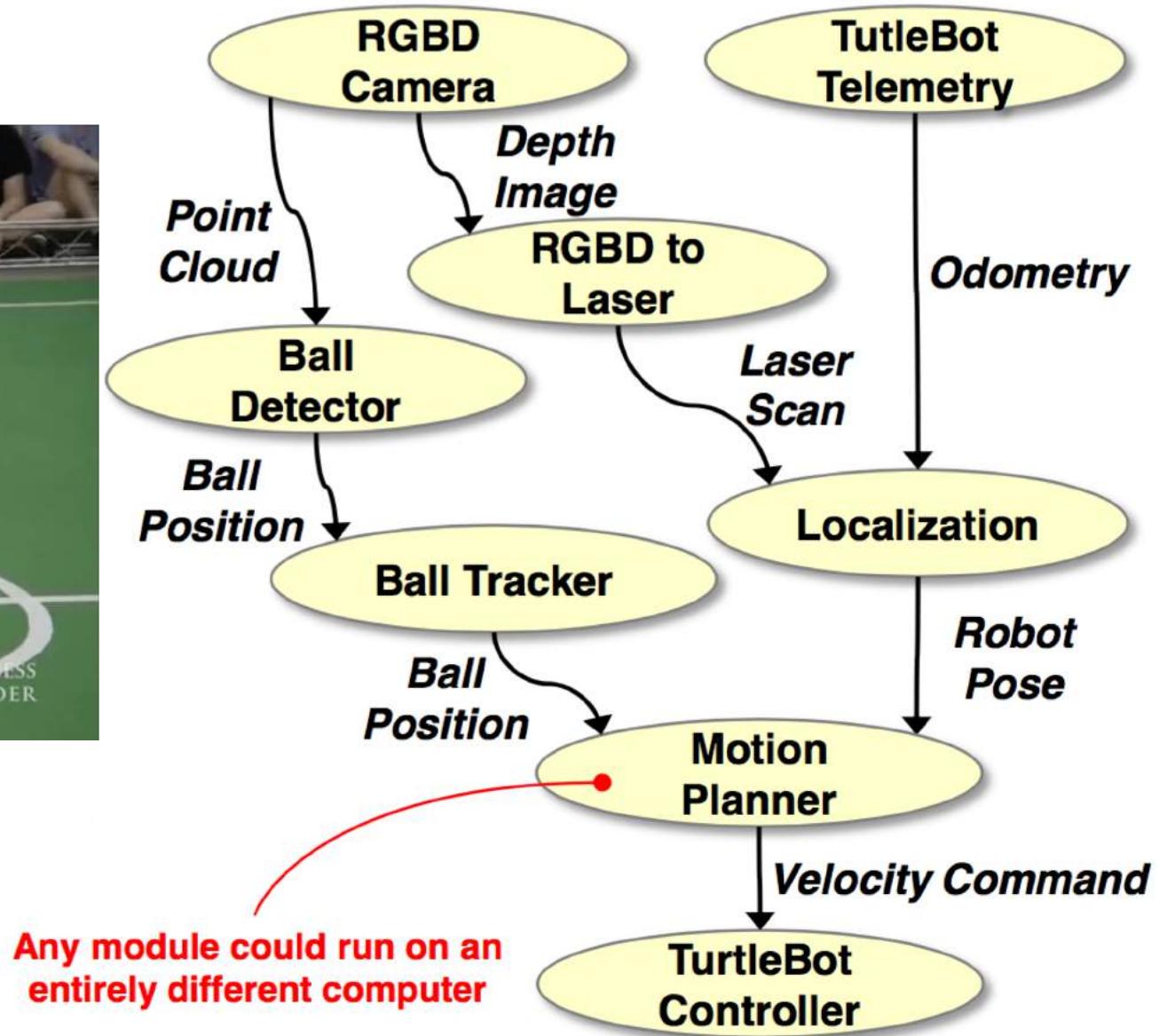
## Ecosystem

- Package organization
- Software distribution
- Documentation
- Tutorials

# Modular, Parallel



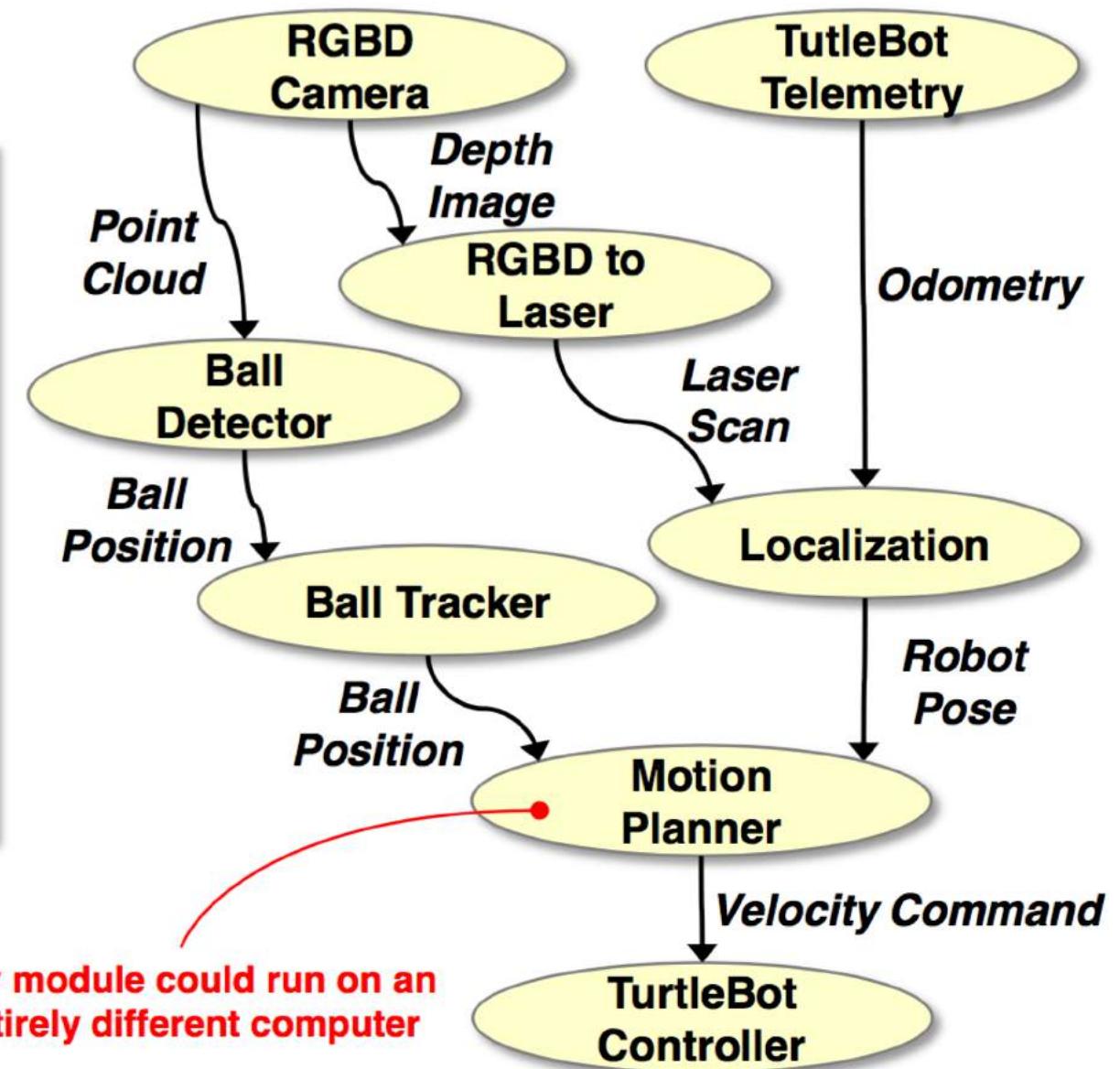
Save of the century



## 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(...)
```

## Modular, Parallel



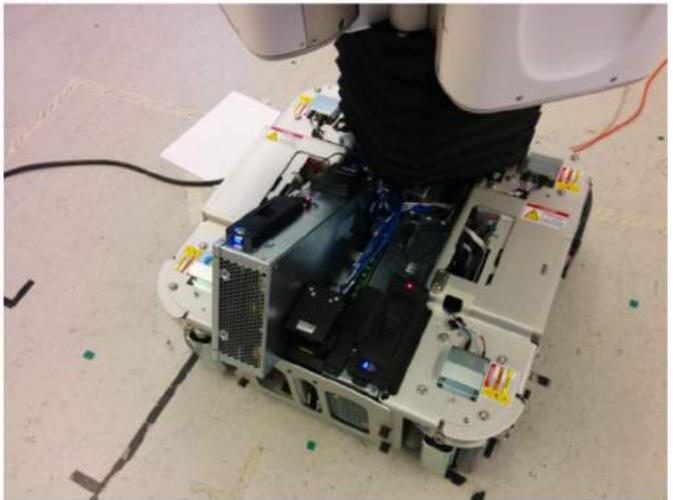
# ROS Philosophy

- **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



# Computational Changes



~1 kW



~20 W



~1 W



<< 1 W

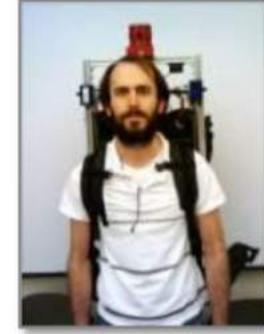
# ROS History

- 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



STAIR I

STAIR II



Morgan Quigley



Ken Conley



Tully Foote



Brian Gerkey

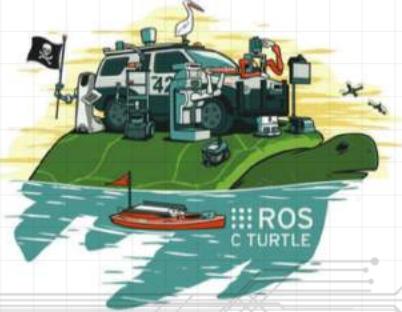


Open Source Robotics Foundation

# ROS distributions



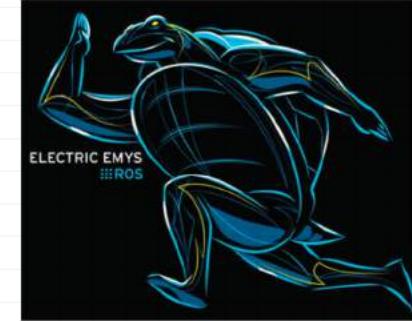
2010



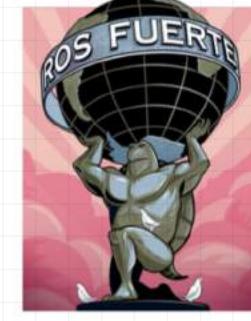
2010



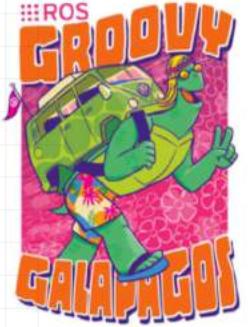
2011



2011



2012



2012



2013



2014



2015



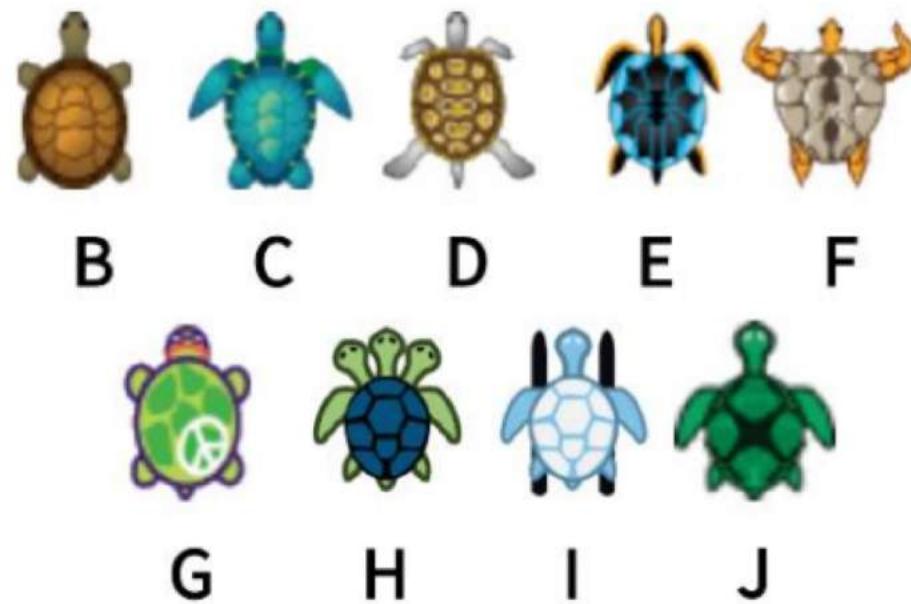
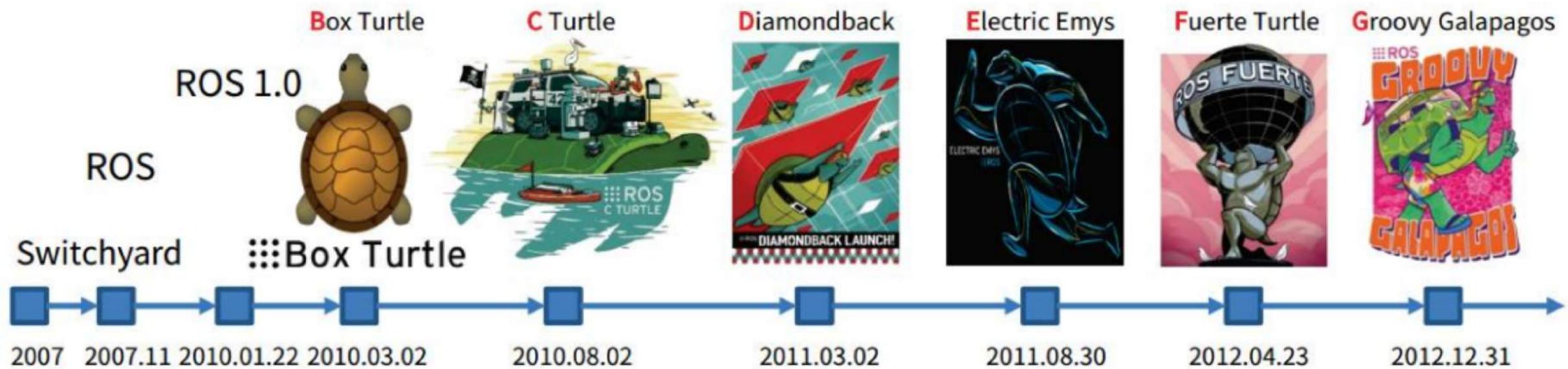
2016



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?

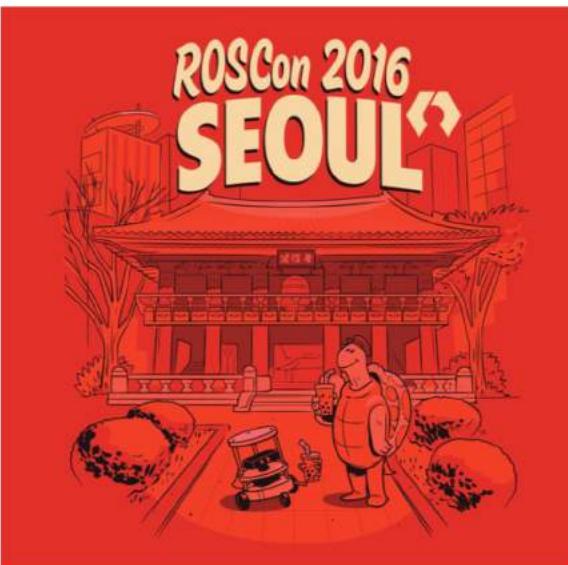
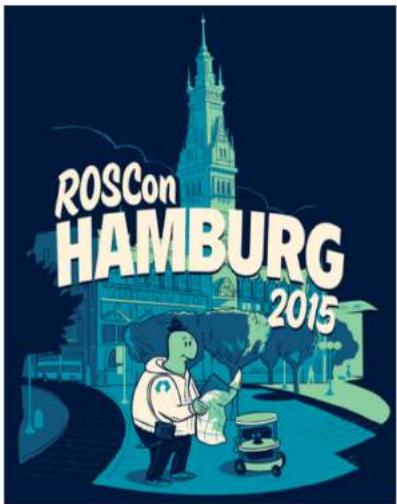
- **ROS.org**
  - Wiki documentation & ROS standards
  - Special Interest Groups (SIG)
  - ROS Enhancement Proposal (REP)
  - ros-users mailing list
- **ROSCon**
- **Shared code repositories**
  - Linked by ROS.org, most moving to GitHub



## ROS Community: **ROS Build System Status**

- <http://www.ros.org/debbuild/indigo.html>

# ROSCon 6 years



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 Tsouroukdissian, 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@jsk.imi.u-tokyo.ac.jp, Fadi Furrer, Geoffrey Hunter, Marc Alban, Sachin Chitta, E. Gil Jones, tarukosu, abubeck, Stéphane Magnenat, Younghun Ju, Julius Kammerl, youhei@jsk.imi.u-tokyo.ac.jp, John Hsu, ueda, tailor, Karsten Knese, ipa-bnm, David Lull, murooka@jsk.imi.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, Ian Paulius, Benjamin Vaid, dorodnic, manabu, Yuto Inagaki, Dorian Scholz, trainman419, Mikael Arguedas, AlexV, Richard Bormann, aginika, Rohan Agrawal, Doug Stephen, warataka, 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.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, Jerome 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.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. Lull, Philippe Hamelin, Antons Rebguns, xaxxon, chadrockey, Shohei Fujii, Sammy Pfeiffer, Sabrina Heerklotz, Eisoku Kuroiwa, Diakopoulos, Dimitri, nakaokat@gmail.com, Matthias Gruhler, Lukas Goldhoorn, Lukas Bulwahn, ipa-cpc, Patrick Mihelich, Jose Luis Rivero, Adam Stambler, yk.at.jsk@gmail.com, unknown, cinexw, facontidavide, dpsolomon, YuOhara, Toni Oliver Duran, Séverin Lemaignan, Simon Lynen, Pavel, jorge, frmw, aleeper, Jason Derenick, Hugo Garcia, Evgeni Raikhel, Eric Wieser, DinnerHowe, Christian Dornhege, Alexander Duda, lazewatskyd, eglijones, Nicho, Jorge, Miguel Sarabia, AliquesTomas, ahoward, Kevin Watts, Kamada Hitoshi, manabu1118, ipa-fxm-fm, Takamasa Sasagawa, Mina Kamel, HannesSommer, Florian Mirus, pvechersky, leibs, Matt Hansen, Jordi Pages, Frederik Hegger, Bruno Brito, Alex Bencz, kentsommer, Yuto Uchimi, YutaKojio, Kurt Konolige, Georg Arbeiter, Austin, nhg-ipa, fmx-db, adam\_lein, Samuel Bachmann, Martin Guenther, Janosch Machowiinski, Tommaso Cavallari, Mattia Racca, Mark Addison, Marc Hanheide, spourmehr, sbertussi, satofumi, eaertbel, Yeong-il Choe, Sarah Bertussi, Adrian Böckenkamp, rguzman1, Ronald Ensing, Maarten de Vries, Borys Tymchenko, kevinwwatts, fmina, cmeyers, Martin Zenzes, Kevin Hallenbeck, DongWook Lee, Benjamin Pitzer, ipa-tif, helsner, francois, Joseph Duchesne, Alex Henning, Tim Niemueller, Christian, ipa-cob3-5, Peter Eykens, Orsten, Sterling G, Axel Kohlmeier, Antoine Hoarau, Alan Meekins, gbiggs, garaemon, Thiago de Freitas, Scott, John Harrison, G.A. vd. 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, ruipimentelfigueiredo, 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, frnw-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, jrutge, 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 Hacinecioglu, 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 Aertbelien, 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 Stavrinos, COB3-Manipulation, Botaao 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, banmasa, Victor Lopez, Surya AMBROSE, Roman Bapst, Rob Wheeler, Rajvi 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 Röhling, Sam Pfeiffer, Robert Krug, Nuno Marques, Mike O'Driscoll, Jeremy Zoss, Eric Cousineau, ElenaFG, Damjan Miklic, Armstrong, Lehi 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, trurl, 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, Kentonuk, Kent Commer, 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, lkaraoguz, 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, zhihao, wwwrob, raw3, 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, mhkarib, 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 Möserlechner, 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, bh5ma..., yoy alex, Yoonseok Pyo, Tatsuya Ishikawa, Stefa Kohlrecher, 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 Keron, Di neemans, Edy, Dorian ScholzN, 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 mizec, fmw-jil, hou, etha, dhood, cob4-7, cmdunkers, chriscrick, calibration, bponsler, babak sistani zadeh, asimay, asadat, andreas, administrator, Yumi, Thomas Zweelfer, 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, pgorcak, 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 Tueylue, 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, velinddmitrov, 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, Marti 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 Moine, 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, Daniel Maturana, Daniel Axtens, Christina Gomez, Chris Foster, Charles Lesire, Arn-O, Alpha laptop user, Alessandro Francescon, , z, xuhao, xaedes, wud, wkentaro, uh-mb, tyounwo, 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, pbheeson, 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-brsu-2-pc1, cwecht, cob3-1-pc2, berger, auboluxin, 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. Monroy, Jason Scatena, Jannik, James Sergeant, Jakob Breuninger, Jake Bruce, Jaime Pulido, Isaac Desu Saito, Intelligent and Mobile Robotics Group, Igorec, IHeartRobotics, Holger Rapp, Hattori, Guy Burroughes, Graeme Yeates, Gautham Manoharan, Frank Slomian, Fran Real, Florian Jordan, Florian Echtler, Filip Jares, Felix Rehrmann, FM, Eric Mulvaney, Enric Galceran, Dino Hüllmann, Dinesh Bolkensteyn, Davide, Dave Bradley, Daniel Seifert, Daniel Pinyol, Daniel Mäki, Daniel Claes, DT, Craig Sherstan, Cory Quammen, Christian Dondrup, Chao Qu, CMP, Brian Hetherman, Brent Yi, Boris\_il\_forte, Bob Holmberg, Bjoern Browatzki, Berend Kupers, Bastian Gaspers, BFALacerda, Aurélien Ballier, André Potenza, Andrzej Pronobis, Andre Volk, Amanda Brindle, Allison Tse, Alan, Adria Gonzalez Esteve, Achim Königs, Aaron St. Clair, 0xff, zyopter, yota, xuhao1, ximo112, worm, william, wghassan, webportal, vp153, virtubuntu, virtual, vaultbot, twiniars, turtlebot, tpratkhanis, tomokurosan, tmdiv, tjadevries, thibaux, tappan-at-git, syedharoonalam, sosentos, somudrog, shooofeh, ryo, ros-devel, rockie, robotnik, rob platt, rjm5066, res, rb1, randoms, philip 14.04, pAlg10, otsubo, oshiro, orangelyn, ojura, nick-alton, nerian-vision, moriarty, minglongli, mike, michael.quinlan, mgerdzhev, m0117248, luca, liz-murphy, igeorge, lemant, kvdesai, kphil, komeisugiura, kojio, kk6axq, kjanesh, kiloreux, khenglee, keulYSMB, kattyokaccho3616@gmail.com, kakehashi, john9000100, jmtatsch, jmachowinski, jksrecko, jdddog, ipa-goa-hh, ipa-bfb-sc, hugbed, henderso, hauptmech, harada, guihome, goa-uq, giusebar, gennaro, ganguly, ftsadmin, frederikhegger, fmw-ms, fmw-br, filip novotny, ferherranz, fabrizioschiano, eugene-katsevman, ethanfowler, ethandreyfuss, endres, efernandez, ed, desire, davidfernandez, daniser, dani, cu-noyvirt, cretaceous-creature, cousins, colin, codebot9000, cob4-11, changxuefeng, buzzshima, browatbn, bricerebsamen, brandon shrewsbury, bona\_jackal, bokinsky, blutack, au, athackst, arthur, arjunmenon, applications, amolbork, aleksey-sergey, a-kako, Yusuke Oshiro, Yuqian Jiang, Yuki Suga, Yuichiro KAWASUMI, Yoshimaru Tanaka, Yohel KAKIUCHI, Wouter van Oijen, Wannes Van Loock, Vinzenz Bargsten, Valkyrie Unit B, Usario, Tomoya Yoshizawa, Tobias Sing, TinneDeLaet, Tim, Thomas Fäulhammer, Thomas Bamford, Theo Devries, Taiji Fukaya, System User, Steven A. Cholewiak, Stefan Profanter, Stefan Kaiser, SomeshDaga, Sina Solaimanpour, Siegfried-Angel Gevatter Pujals, Shotaro Terato, Shih-Yun Lo, Shadow Hand at LIRMM, SeiUeno, Sebastian Pütz, Sebastian Boettcher, Sean D Matthews, Scott Paulin, Sauce10, Sascha Wirges, Sascha, Samuel Carlsson, RyuYamamoto, Ryo Terasawa, Ryan Luna, Roy Shilkrot, Ross Taylor, Rosen Diankov, Ron Tajima, Romain Reignier, Rohan Bhargava, Robot User, Roberto, Raikhel, ROS, Procópio Stein, Pompolis, Po-Jen Lai, Piotr Trojanek, Pierre Hauweele, Philipp Tscholl, Patrick Leary, Paul, José Pereira, Nobuhiko Miyamoto, Nicolas Bigaouette, Nathan Koenig, Nantas Nardelli, Nadya Ampilogova, Murray Anderegg, Munjal Desai, Miller, Bradford W (GE Global Research), Mikkel Rath Pedersen, Mikhail Medvedev, Miguel Prada, Michael J. Stevens, Michael Karg, Michael Johnson, Michael Janssen, Mehmet Murat Sevim, Maxime Rio, Max Schettler, Matthew Bries, Matthew, Matt Richard, Matt Alvarado, Matias N. Matei, MartinPeris, Martin Szarski, Markus Bader @ virtual box, Marius Fehr, Marjel Stuttgen, Man Essinger, MLefebvre, Lukas Jelinek, Luca Marchionni, Loy, Lorenzo Rosa, Lorenzo Riano, Leopold Palomo-Avellaneda, Leonard J, Leon Ziegler, Leif Berg, Kurt Christofferson, Kunio Kojima, Kunal Tyagi, Krishneel, Koji Terada, Kobuki Brain No. 3, Kim ByeongChang,



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. Mateo, CHILI Demo Corner, Brian, Bo Li, Blake Anderson, BennyRe, Benjamin Hitov, Benjamin Brieber, Benjamin Blumer, Ben Struss, Ben Cohen, Ben Ballard, Azamat Shakhimardanov, Alyish Wrench, Ashish Raste, Arturo Martín-de-Nicolás, Arnaud TANGUY, ArjunMenon, Anurag Makineni, AndyZelenak, Andrew Blakey, Andreas Paepcke, Aleksandrs Ecins, Ahmet Sezgin DURAN, Adrian Yuen, Adolfo Rodriguez Tsouroukdessian, Adel Fakih, Aduin Kauch, Achim, AGY Test, 85pando, 7bit, 2scholz, 越 漢居, 寺田 耕志, 勝者神優 (Jean Nassar), "chcorbato", zzh, yuyu2172, yukihiro saito, yswhynot, youtob-hbrs3-pc1, yotabits, yk.at.jsk@gmail.com, xpharry, woshidag, wmcmanhan, wken, wheeled\_robin, ygdling way, egran lich watah, Yangson312, wanglb, Volkandre, vmayoral, vliedel, vladrotea, vision, varunns, vanurag, vadmin, unhelkar, uliklank, uhr, ubiquity, tzu.ta.lin, todorangrg, tif, tattom, t-katami, stgagnon, spaghetti-, souravran, shehzad, ser=mvise, sepol, smunk2, uel, schnijer, sandeep, situacion sanh, ryll, russevans, ruffsl, rsinnet, rphilippsen, roych0111, rosuser, roboskin, robinett, rob@work robot, rmb, rlklaser, richard-virtualros, rheidrich@uni-koblenz.de, rhd, rg828179, raw3, pushittodc, psimona, procoplostein, poggenhans, pmania, plieningerweb, phuicy, philOstine, phil, pgrice, pfiffnst, petermitrano, peter mitrano, pcb, pastor, parijat10, palmieri, osrf, orocos@dpinol.com, ohendriks, ntenenz, nschoenhals-cpr, notheworld, nobbis, nicolasWDC, nevernim@gmail.com, nelhayek, negre, neo, natem345, nao2853, nakaokat, mzaiady, mxcreator, muratsevim, mttamtam, mthz, mryellow, mrappapo, mppics, mllofriu, mizux, mitya, mfueler, mech-user, means8717, mdl-ws, mchamoux, mcgann, mbrindle, mboukamp, max, matt3o, mathosomal, matei, mariusmuja, m-ihsida, lucasw, lth, lrasinen, louise, linzhibo, liang, lgerardSRI, kur, koji\_terada, koji, kochigami@jsk.imi.i.u-tokyo.ac.jp, kmhallen, kkiyenga, kiwi.net@mac.com, khancyr, kevin, kenji0919, karsten1987, k-ysuda@1433-ysuda3, junior, juichung kuo, jsk-members, jscholle, jsanch2s, jotaemesousa, joseph, jondy276, jokla, johaq, jmapariciorobotnik, jimv, jim-v, jeppewalther, jep, jeff-o, jeff, jczaornowski, jbrindza, jannikb, jannik, jan0e, j\_bohren, ipa-rmb-pz, ipa-mjp, ipa-mig-hrm, ipa-lth, ipa-cob4-7, ipa-bfb, ioryz, iche033, landanforth, hugo, hris2003, honeytrap15, hokuyo@free53.hokuyo-aut.co.jp, hokuyo2@free53.hokuyo-aut.co.jp, hkanda, hgaiser, helen, hdang, hcjung, hamalMarino, guan, goodfellow, goatfigpc, gjc13, gerkey@eb33c2ac-9c88-4c90-87e0-44a10359b0c3, gborque, g\_gemignani, francesco-romano, fmder1, fkie, fivef, finostro, fernando, felix-kolbe, federico-b, fau-mjp, evan.exe@gmail.com, emijah.s@gmail.com, emijah, edsfocci, duhadway-bosch, dpiet, dougsm, dontsovcmc, dlaz, dhiraj dhule, develop, demo@cob3-1-pc1, demo, dawid, david libman, davembradley, danthony06, danno, daniel, cvs2svn, ct2034, croadfeldt, crazyorc, cottsay, colaed1@gmail.com, cob3-2 admin, cob-hardware-test, ckross, chuck-h, chris-smith, chipironcin, chesternimiz, chengshy, ccny-ros-pkg, cberner, caguero, buschbapti, burrimi, bradski, bona, bobbyshashin, bikramak@aandkrobotics.com, bhimberg, bergercookie, bardo91, bakui, babu, avaziri, au@pr1040, anonymous, andz, andreeatulbure, andre-nguyen, anderwm, amauray, akgoins, akalmbach, ahendirx, agoudar, aduda, adelarosat, achronop, abrzozowski, aborkar, Zilvinas, Yuval Boger, YuqianJiang, Yuma.M, YuehChuan, Yota Ichino, Ying Lu, Yifei Zhang, Yasuhiro Ishiguro, Yam Geva, WouterBancken, Woody Rousseau, Woodrow Shen, Wolfgang Hess, Wolf Vollprecht, Wilm Decre, Willy Lambert, Willian Galvani, William McMahan, William Hilton, Will Baker, Wiebe Van Ranst, Wayne Chang, Wang Jinliang, Wade5566, Volker Grabe, Vladimir Petrik, Vladimir Gamalian, Vincenzo Comito, Viktor Kunovski, Victor Westerhuis, Victor Savu, Victor González-Pacheco, Valsamis Ntouskos, Uwe Kindler, User, Tyler Slabinski, Tycho Hertogs, Tushar Dadlani, Turtlebot, Tracey Spicer, Tomaz Solc, Tom Miller, Tom Howe, Tobias Fischer, Tobias Bär, Tobias Berling, Tim Fröhlich, Thomas Zwölfer, Thomas Watters, Thomas Lerman, Thomas Emter, Thaddeus Taylor, Tessa Lau, Tatsushi Karasawa, Tarek Taha, TSUYUSATO Kitsune, Sven Albrecht, Stuart Alldritt, Steven! Ragnarök, Steve Vozar, Steve Levine, Steve Le Roy Harris, Sterling McLeod, Stephen Street, Stephane Poirier, Steffel Fénix, Stefano Probst, Stefan Otte, Stefan Menzel, Stefan Haase, Stefan Fabian, Stefan Eilemann, Stefan Dörr, Srinivas Kerekare, Simon Pelletier-Thibault, Shin'ichiro Nakaoka, Shin, Shimomura Ryo, Shadow Hand at Macedonia, Sergio Ramos, Sergi, Sebastien Mamessier, Sebastian Wagner, Sebastian Rockel, Sebastian Blumenthal, Scott Ware, Scott McCain, Scott Martin, Scott Greenberg, Schulz, Savant Krishna, Satoshi Danno, Sascha Arnold, Santiago Castro, Sandra Reitinger, Salah-Eddine Missri, SPENCER-Freiburg Laptop, SEBASTIAN-GM, Rémi Barraquand, Ryosuke, Ryoeo Ueda, Ruffin, Román Navarro, Roland Philippse, Rohan, Rodrigo Chiossi, Robot, Robin Vanhove, Rimco, Rich Wareham, Ricardo Ortiz, Rezzie, Realtime Dev, Ravi Prakash Joshi, Rares, Rami, Rainer Kuemmerle, Raghav Khanna, ROS-Industrial, Qiao Huang, Pyo, Production, Priyanka Dey, Priyam Parashar, Prateek Chaudhry, Piotr Orzechowski, Pino Toscano, Philippe Capdepuy, Philipp A. Baer, Philip Miller, Phil Osteen, Peter Pastor, Peter Lehner, Peter Han, Peter Gao, Pete Willemsen, Perrine Aguiar, Paul Furgale, Paul Dreik, Patrik Paranhos, Patrick de Kok, Patrick Merz Paranhos, Patrick Goebel, Pat Marion, Paco Dupont, PRJ, Otsubo Satoshi, OtaLab, Oscar Lima, Oliver Ou, Oleksandr Lavrushchenko, Okke Hendriks, ObiWan, Notou, Ning Wang, Ning Ren, Niharika Arora, Nicolas Eyssette, Nicolas, Nicola Castaman, Nick Haes, Nican, Neowizard, Nathan Bellowe, Naren Dasan, Naoki-Kameyama, Murilo Belluzzo, Mrinal Kalakrishnan, Morten Kjærgaard, Moritz Tenorth, Mohammed El-Ziqzawi, Mohamed Al-Zaiady, Mizux, Mirs King, Mirko Ferrati, Mirko, Minsu Kim, Ming Gao, Milan Vukov, Mike Weible, Mike Lautman, Miikka Koskinen, Mihai Morariu, Mihai Dolha, Miguel Bernal Marin, MichelaA, Michael Vistein, Michael Koval, Michael Kopp, MiMIC, Mehdi, Mayank\_Patel, Max@racket, MattyG, Matthieu Herrb, Matthias Füller, MatthewRueben, Matteo Murtas, Mathieu Monney, Masaya Kataoka, Masahiro Bando, Marynel Vazquez, Marvin Schmidt, Marvin B, Martin Voelkle, Martin Peris, Martin Llofriu, Martin Gerdzhev, Martin, Markus Roth, Markus Neuner, Marieke Copejans, Maria, Marek Fiser, Malte Langosz, Malcolm Mielle, MahsaP, Lukasz Wielgosz, Luigi Freda, Lucas Potter, Lucas, Luca Cristoforetti, LiohAu, Lingzhu Xiang, Lincoln Lorenz, Leonard Gerard, Le-Fix, Latitude OBC, Lasse Rasinens, Lasse Einig, Lars, LIU Tianbo, LIAO Qinghai, Kun Li, Krit Chaiso, Koralgoll, Kopias Peter, Klaas Gadeyne, Kim Mathiassen, Kim Heecheol, Kevron Rees, Kevin Allen, Keshav Iyengar, KentaKubota, Kenn Sebesta, Kazumi Malhan, K.mura, K. Kimoto, Justin Thomas, Justin Bronder, Juntaro Tamura, Julius Gelšvaras, Julius Bullinger, Julian Schrittweiser, Juergen Sturm, Juan Camilo Gamboa Higuera, Josiah Taylor, Joseph Martinot-Lagarde, Jose Luis Sanchez Lopez, JoonasMelin, Jonathan Weisz, Jonathan J Hunt, Jon Fink, Jon B, John Morrissey, John Meyer, John Macdonald, John M. Daly, John Hoare, John, Joao Avelino, Jesse Clark, Jeremy Nicola, Jeremy Kerfs, Jeremiah Via, Jeff Eberl, Jean-Christophe ROUX, Jb DOYON, Javier Hidalgo Carrio, Jason Ziglar, Jarvis Schultz, Jared, Jana Pavlasek, Jan-Niklas, Jan Škoda, Jan Bacik, Jan, Jamie Diprose, James Arnold, Jakob, Jailer, Jacob Perron, Jacob Panikulam, Jacob Mason, Jacob Carse, J.A. van Egmond, Isura Ranatunga, Ismo Puustinen, Intermodalics, Immanuel Löwenstein, IanTheEngineer, Ian Taylor, Hugo Boyer, Honore Doktorr, Hong Yang, Hiroki-Goto, Hernan Badino, Henning Kayser, Helio Perroni Filho, Harsh Pandya, Harry Pan, HanjunSong-Fetch, Hanjun Song, Hai Nguyen, Gustavo Velasco-Hernández, Gustavo Goretkin, Gustave Monod, Guillermo Manzato, Guillaume Papin, Guillaume Autran, Guiherme Affonso, Guglielmo Gemignani, Glass Bot, Gil Jones, George Andrew Brindeiro, Garrett Brown, Gabrielius Mickevicius, Fugu user, Frank Hoeller, François-Michel De Rainville, François Chataligner, Format Bot, Filippo Basso, Ferdinand Jovan, Felix Burget, Filip Marti, Fatih İnan, Fahmi Akbar Wildana, Fabien C. Y. Benureau, Fabian Poggenhans, FIXED-TERM Hausman Karol (CR/RTC1.1-NA), Evangelos Vazaios, Ernesto Corbellini, Erkan, Erik Berglund, Eric Zavesky, Eric Timmons, Eric Marsh, Emili Boronat Roselló, Ellon Mendes, Elias Mueggler, Egbert van der Wal, Edgar Riba, Eagle Jones, EC TF Bind account, Dylan Vaughn, Dupont Paco, Duncan Calvert, Dr. Konstantin Schauwecker, Dominick Vanthienen, Dmytro Poplavskiy, Dmitry Mastynkin, Di Zeng, Detlev Zundel, Deric, Austin C, Derek, Denvo, Denise Eng, Dejan Pangeracic, Dawid Piotrowski, Davide Tateo, David Seaward, David Lavoie-Boutin, David Avedissian, Dave Sandage, DarkDemiurg, Daniel Snider 'Y, Daniel Reuter, Daniel Neumann, Daniel Kühn, Daniel Angelov, Dan Solomon, Dan Ambrosio, Daichi Yoshikawa, DLu, CyrillePierre, Connor Brew, Clyde McQueen, Chuck Claunch, Christopher Schindlbeck, Christopher Hrabia, Christopher D. McMurrrough, Christopher Bradley, Christoph Schroeder, Christoph R, Christoph, Christian Reinhard, Chris Roadfeldt, Chris Lamb, Chien-Liang Fok, Chi Wun Au, Chad Attermann, CatherineH, Carnegie Robotics LLC, Cappy Pitts, CanMoveIt, CTU robot, C. Andy Martin, Butch Slayer, Brian Holt, Brandon Shrewsbury, Brandon Morton, Borkar, Amol, RobertForever, BobbySHEN, Bob Davies, Bingham, Brian S, Benni, Bener Suay, Benedikt Ortelt, Bei Chen Liu, BacikJan, Avio, Aurelien Ballier, Augusto Luis Ballardini, Au, Arvin Asokan, Arnold Kalmbach, Arnaud Degroot, Anwar, Anup, Antonio Franchi, Anthony J. Bentley, Andy Li, Andy, Andrew Wagner, Andrew Clough, Andreas Lawitzky, Andreas Köpf, Andreas Hertle, Andreas Daniel Antener, Andreas Breitenmoser, Andreas Bircher, Andrea Tagliabue, Andre R, Andre Phu-Van Nguyen, Andersw88, Anass Al, Ammar Najjar, Amaury Nègre, Alpen-Adria Universität Klagenfurt - Networked and Embedded Systems, Ali Unwala, Alexis Wieland, Alexis Paques, Alexander Stumpf, Alexander Shishkov, Alexander Perepelkin, Alexander Krupenkin, Alexander Hagg, Alexander Bulychev, Alex Sorokin, Alex Rodrigues, Alex, Alejandro Merello, Alain Sanguinetti, Alain Minier, Akiyoshi Ochiai, Akio Shigekane, Akin Sisbot, Aero, Adnan Munawar, Adnan Ademovic, Adirio, Add tuckarms, Adam Lee, Adam Hachey, Adam, Aaron Miller, ARC Lab Machine 02, =Piyush Khandelwal, 1r0b1n0, (no author)

Thank you! 3

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



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

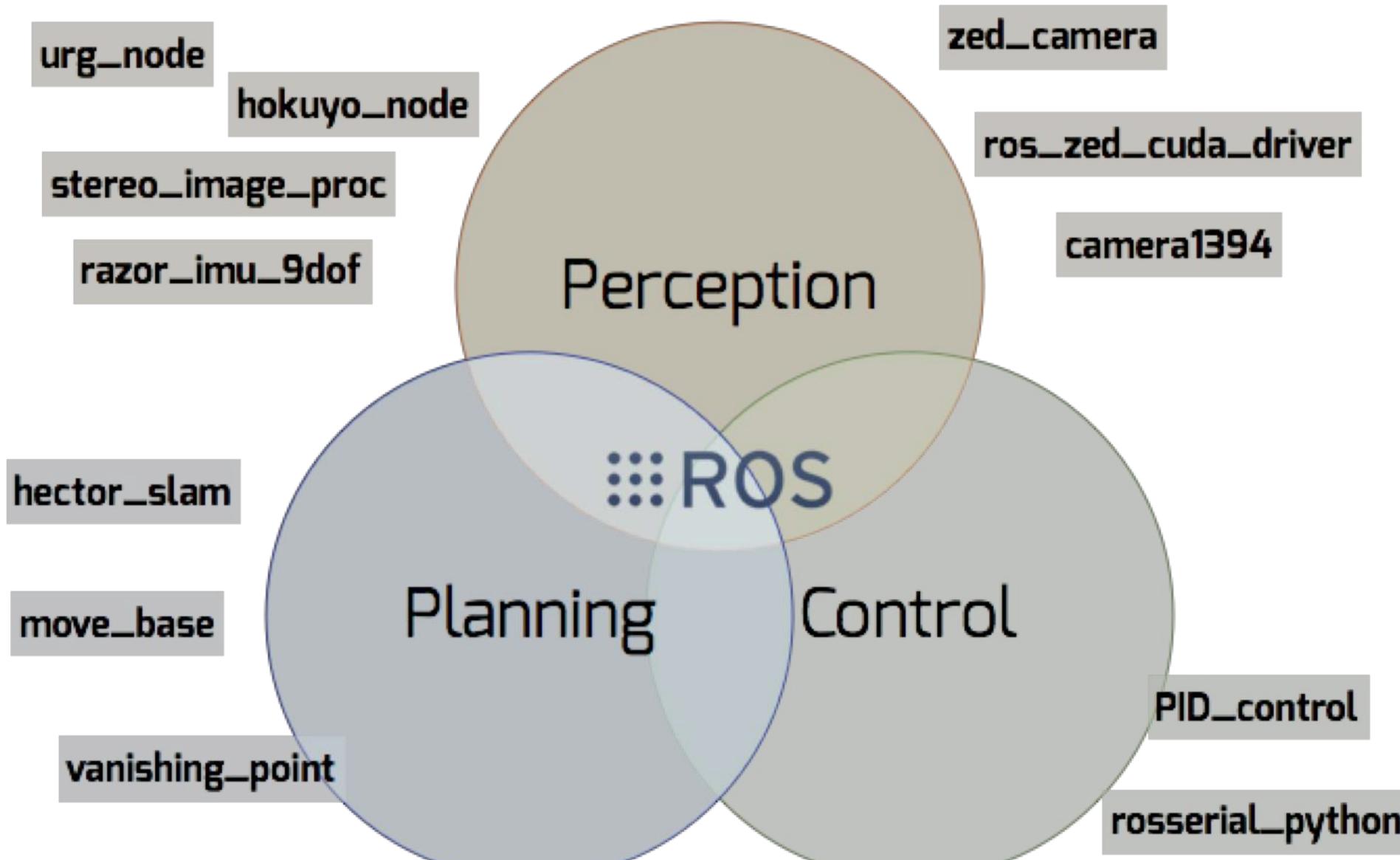
## AUTOMATED DRIVING WITH ROS AT BMW.

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

**BMW  
GROUP**

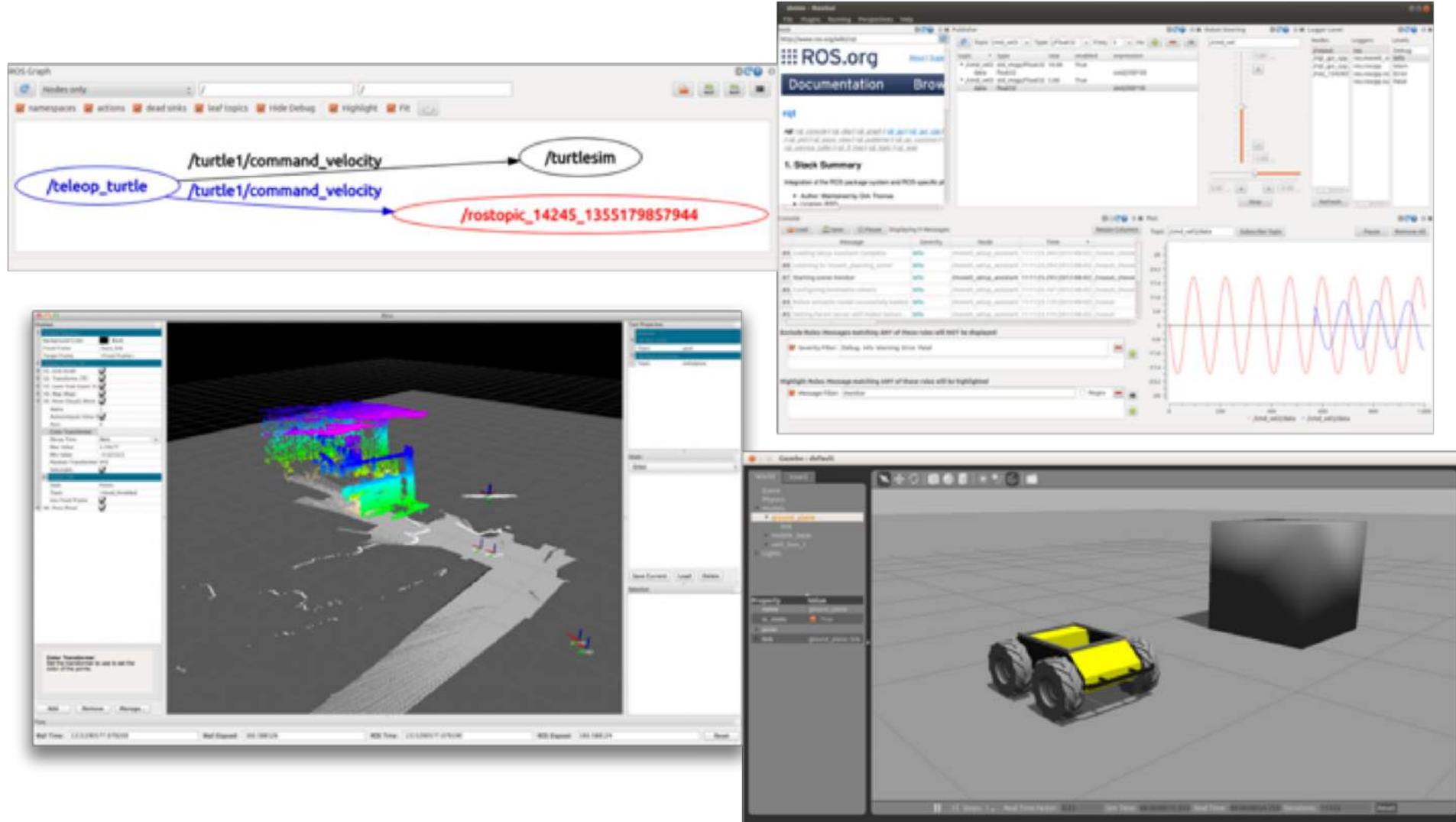


# ROS Capabilities



# ROS Tools

Visualization, debugging and diagnostics, logging, and simulation

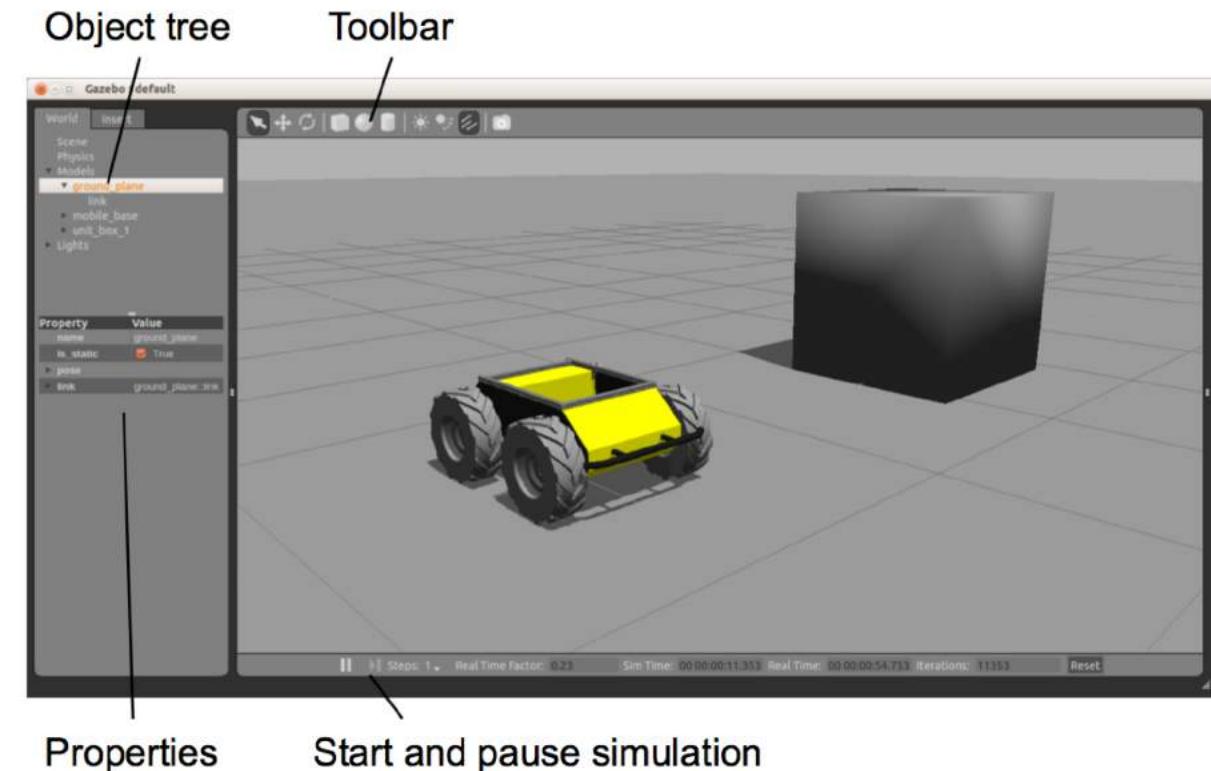


# Gazebo Simulator

- 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
```



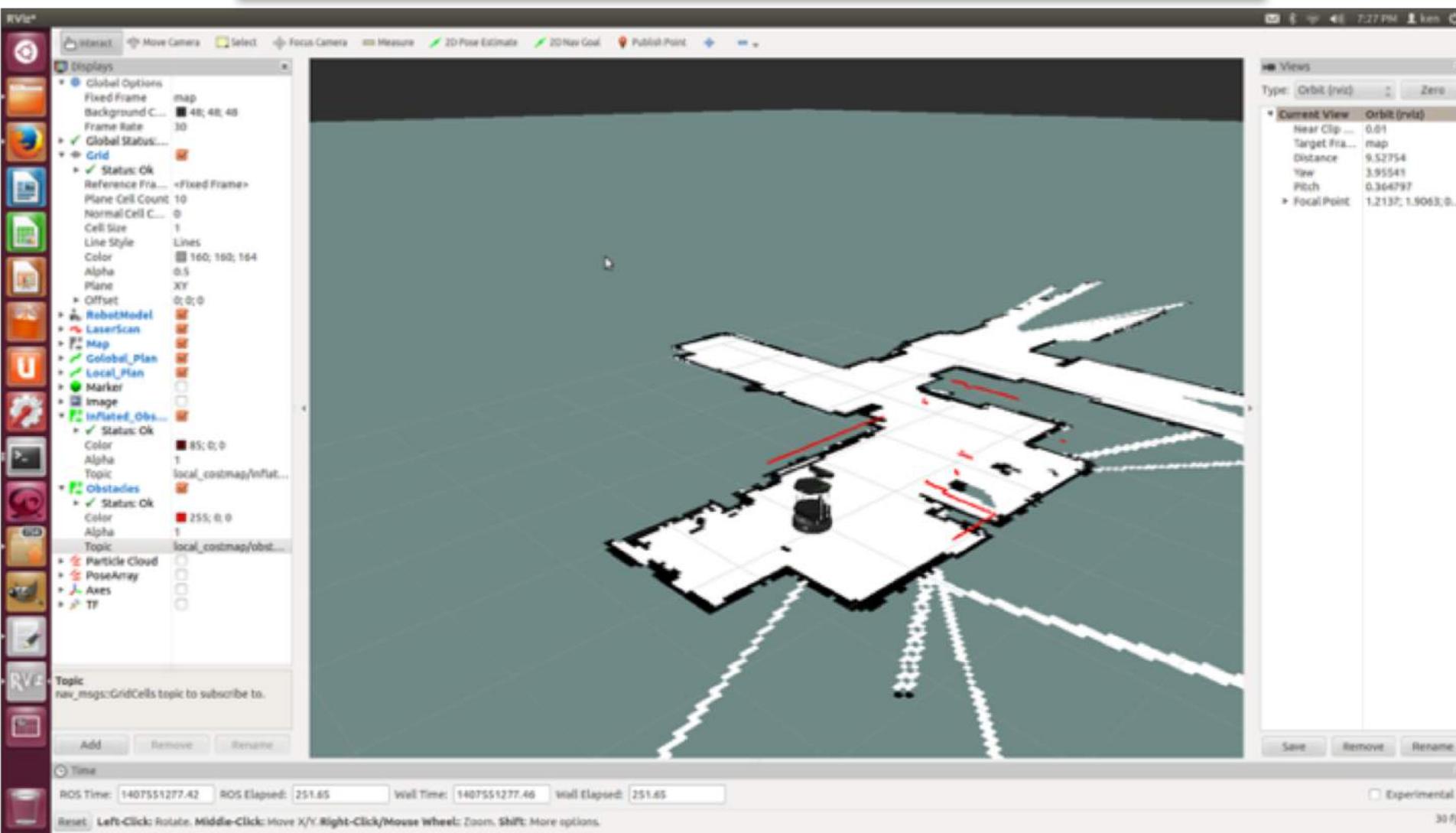
More info

<http://gazebosim.org/>

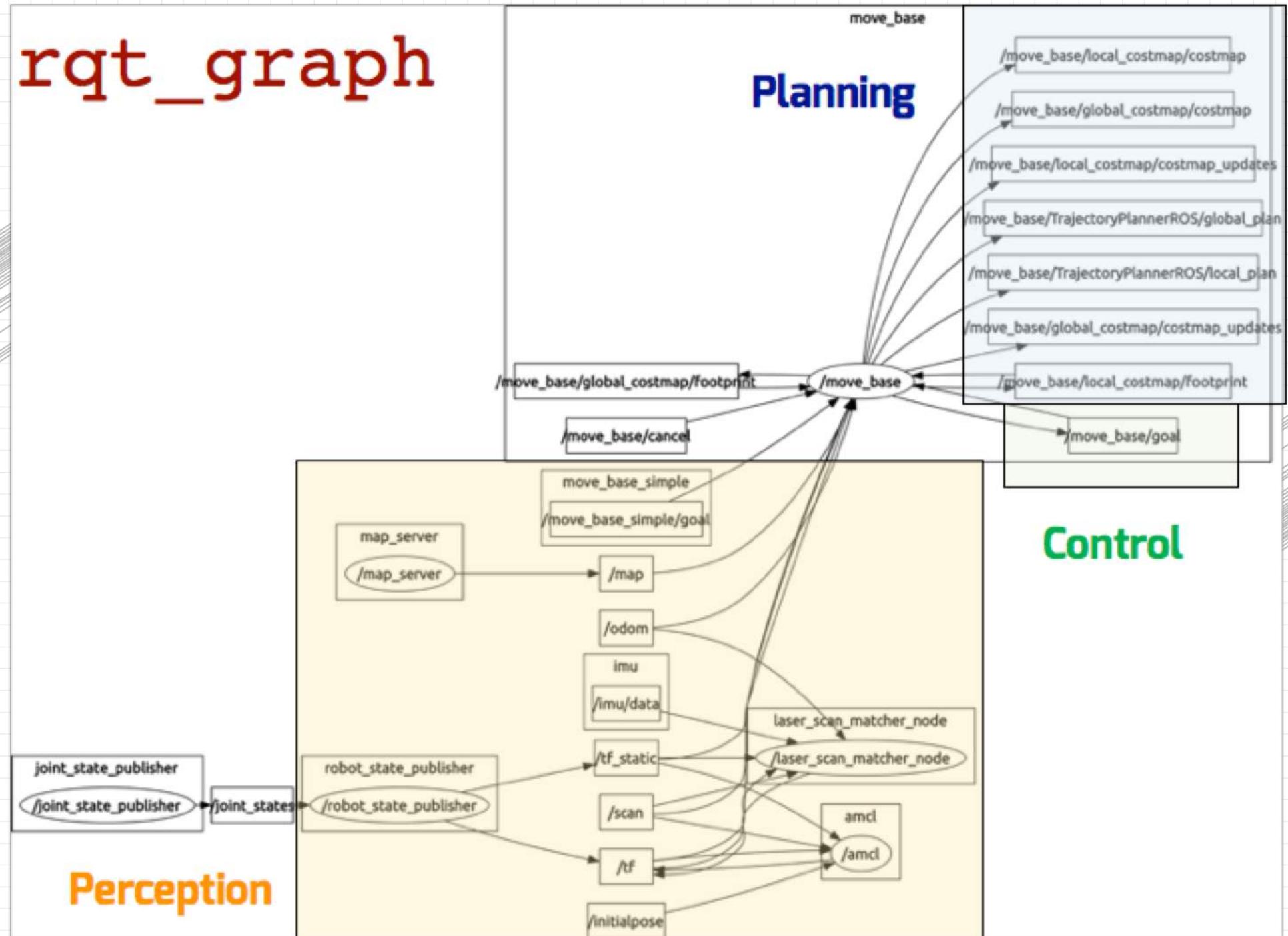
<http://gazebosim.org/tutorials>

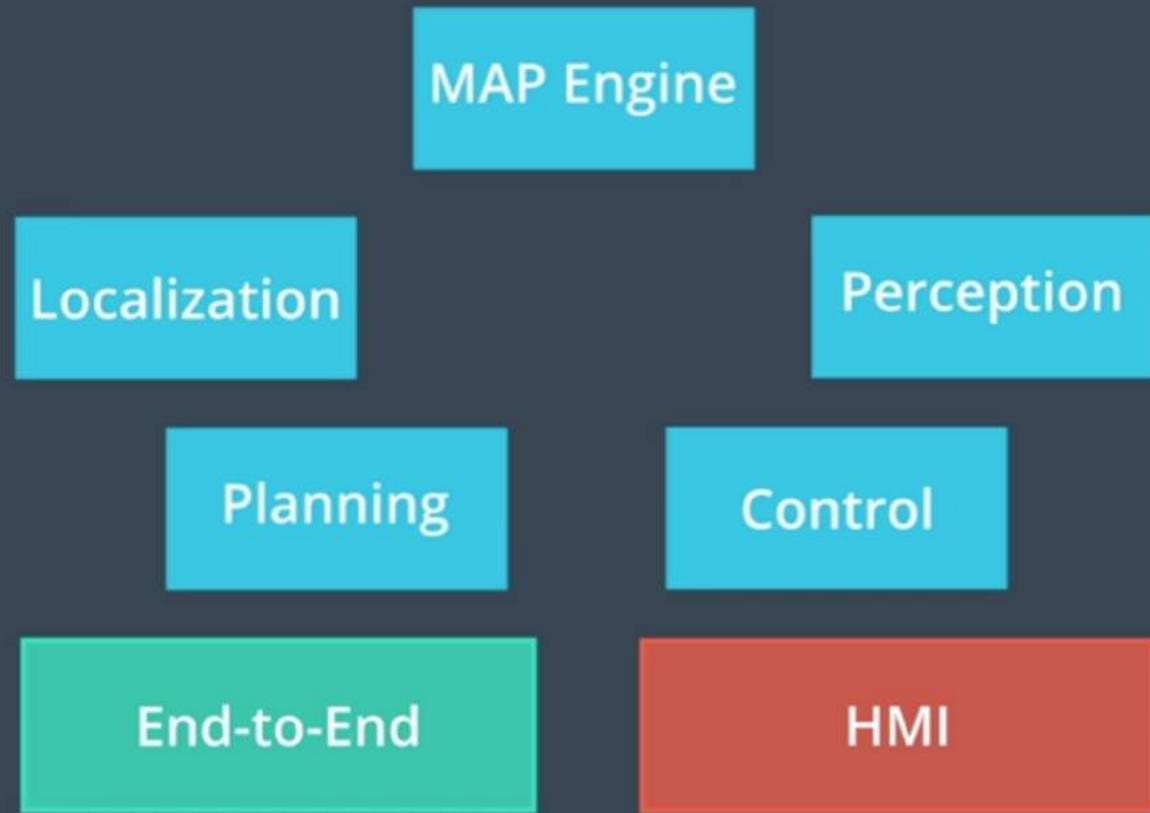
# 3D visualization tool: `rviz`

```
$ rosrun rviz rviz
```

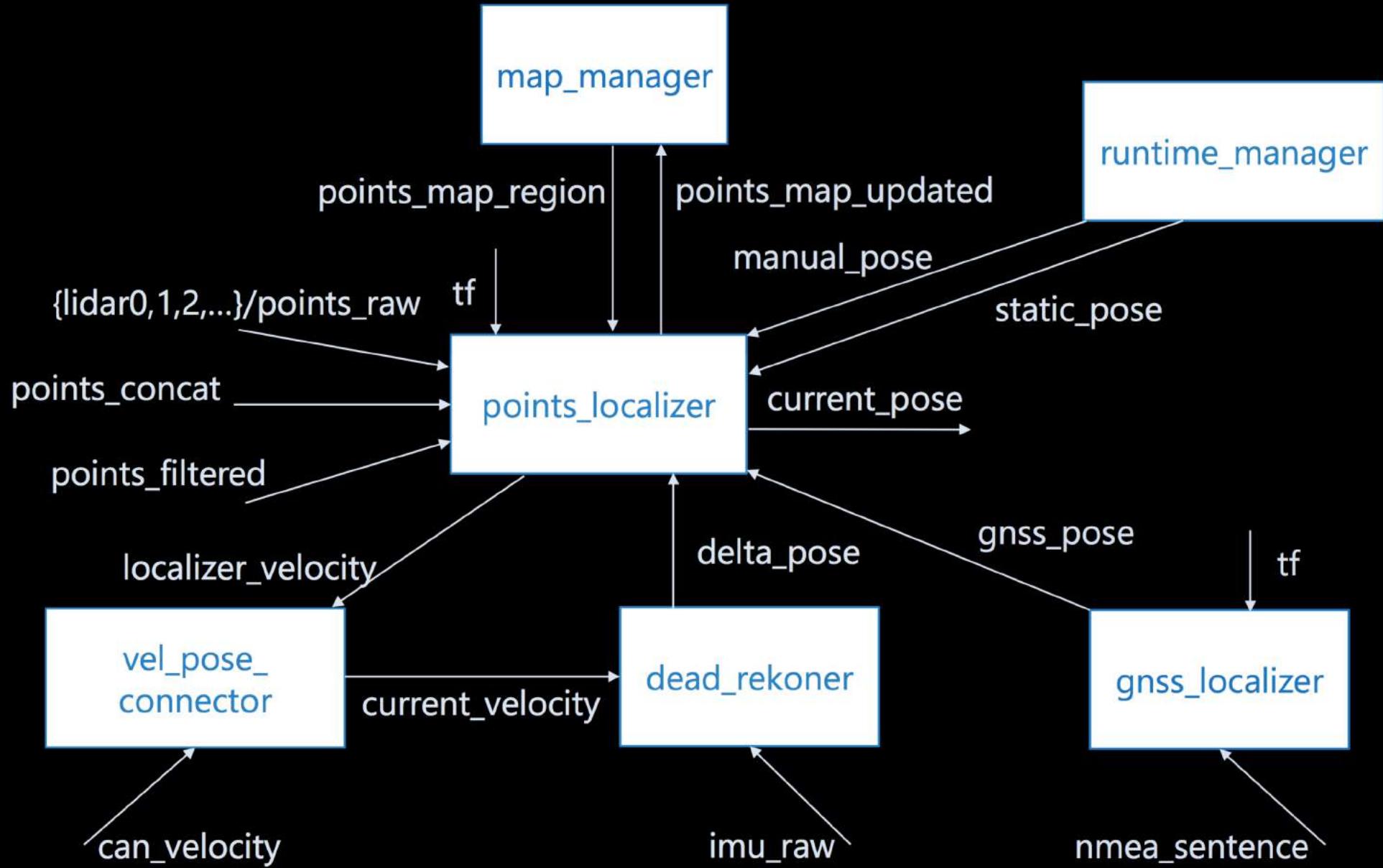


# rqt\_graph

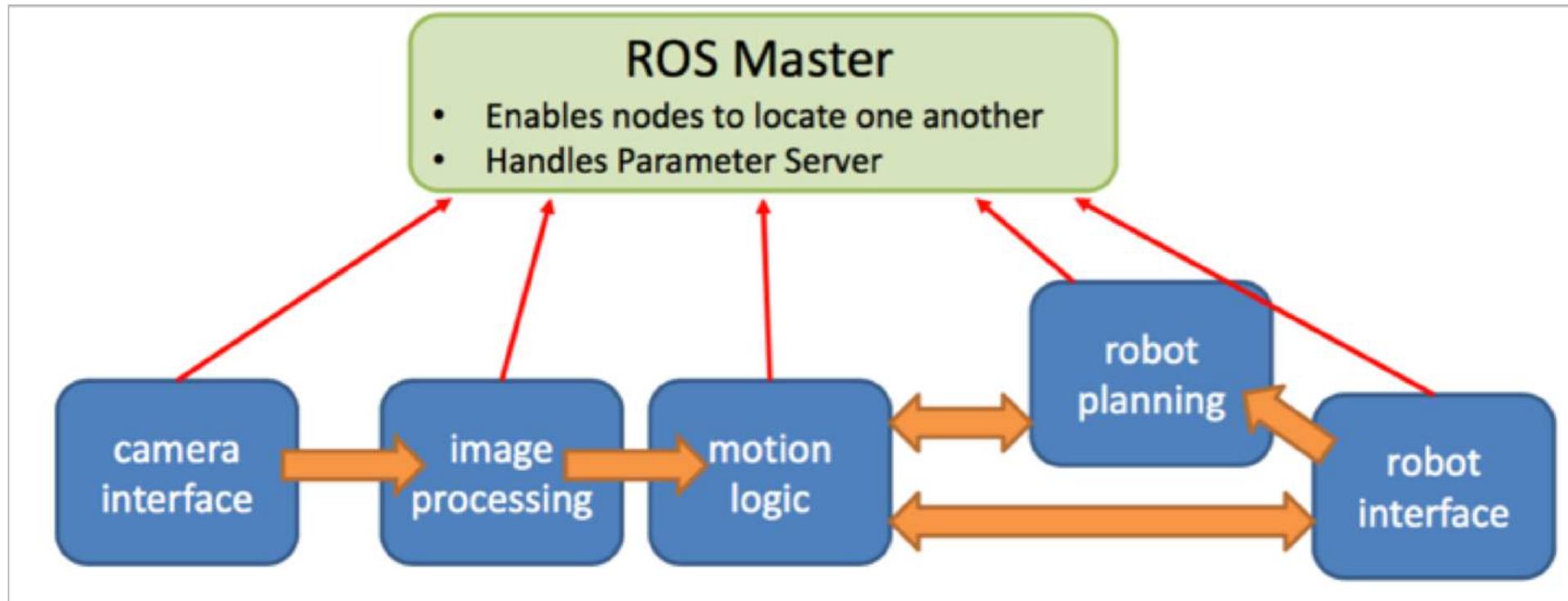




# Packages Example (Localization)



# 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

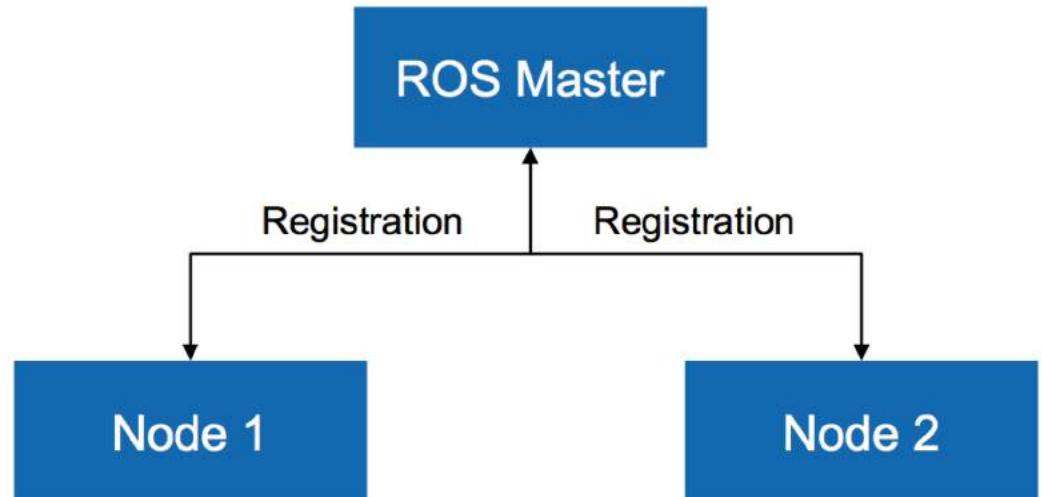
```
> rosrun package_name node_name
```

See active nodes with

```
> rosnodes list
```

Retrieve information about a node with

```
> rosnodes info node_name
```



More info

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

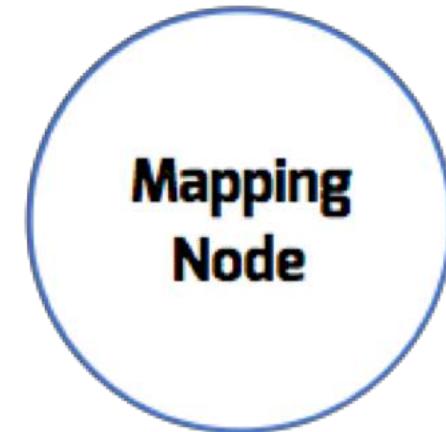
# ROS: Topics

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

They are for **streaming data**



Publishes on topic: Scan



**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

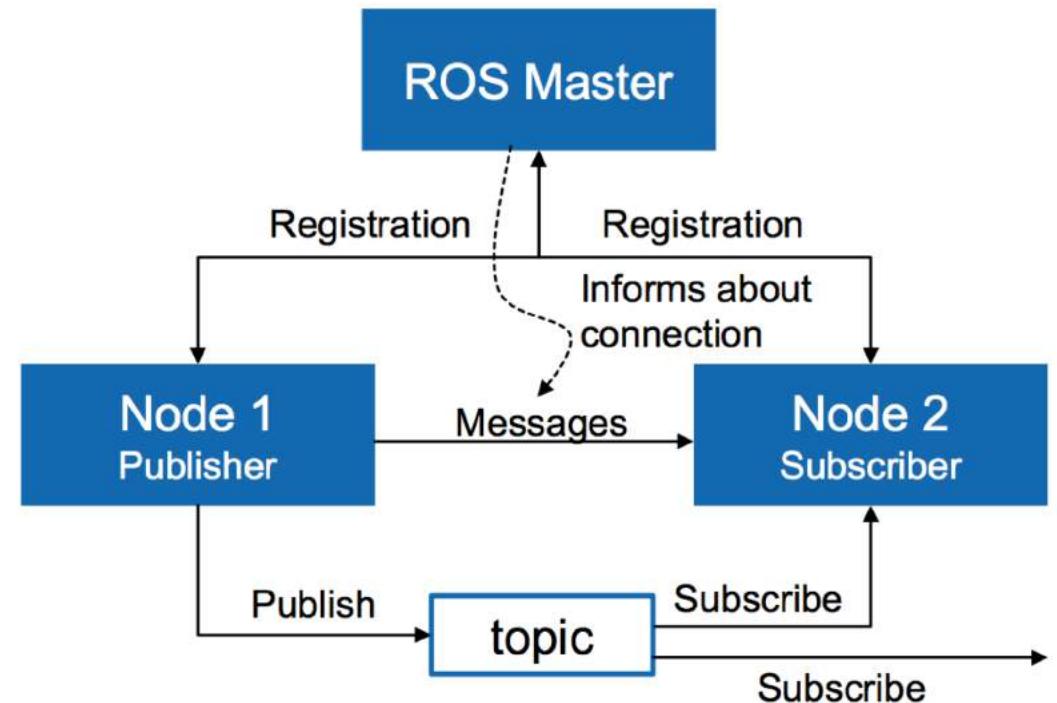
```
> rostopic list
```

Subscribe and print the contents of a topic with

```
> rostopic echo /topic
```

Show information about a topic with

```
> rostopic info /topic
```



More info

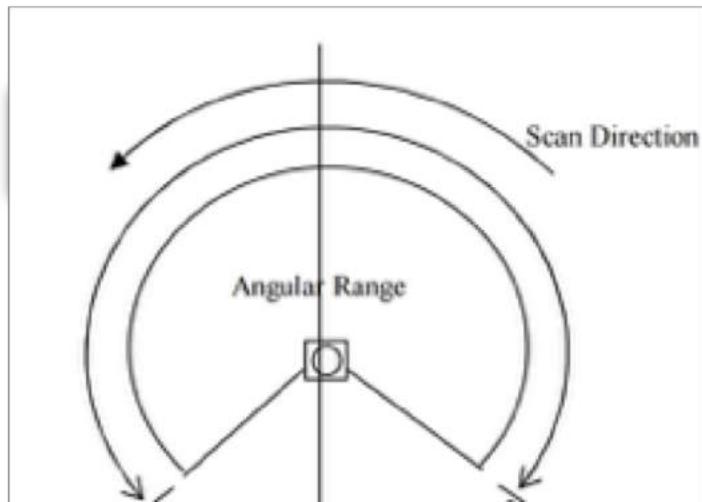
<http://wiki.ros.org/rostopic>

# 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

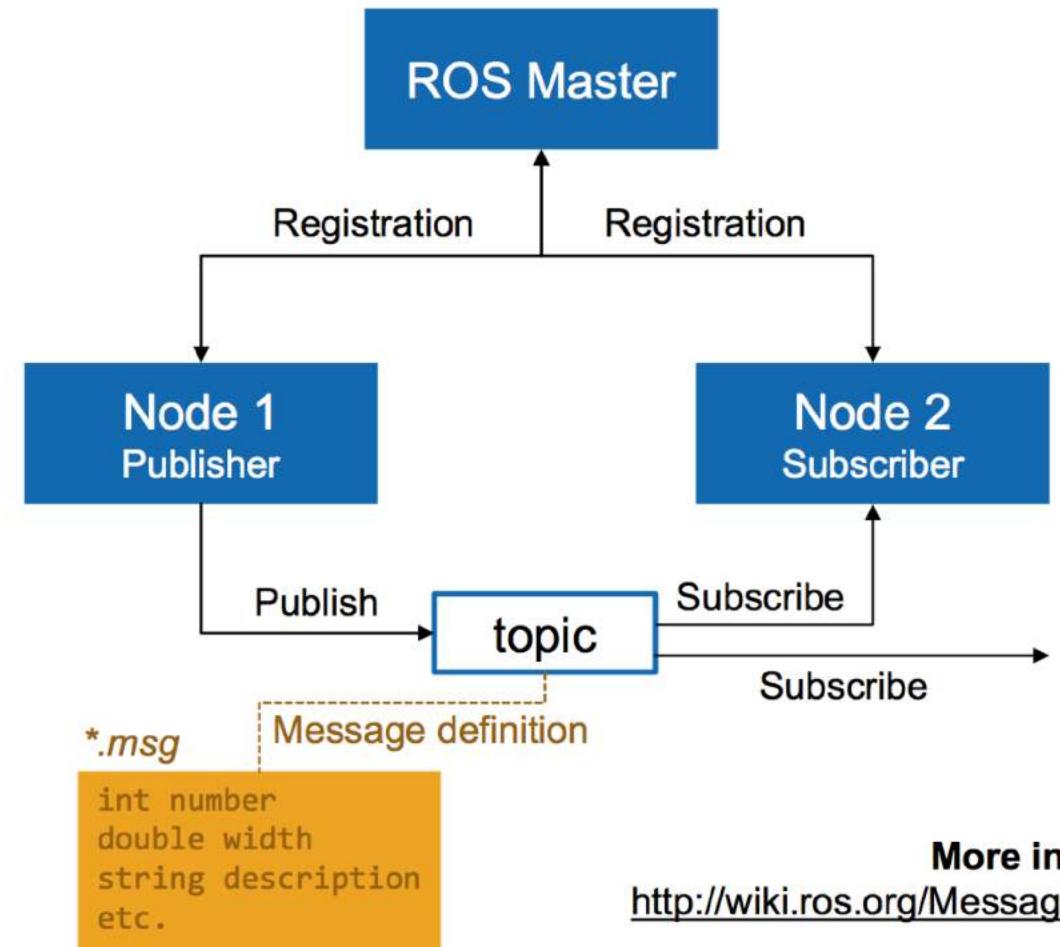
- Data structure defining the *type* of a topic
- Comprised of a nested structure of integers, floats, booleans, strings etc. and arrays of objects
- Defined in *\*.msg* files

See the type of a topic

```
> rostopic type /topic
```

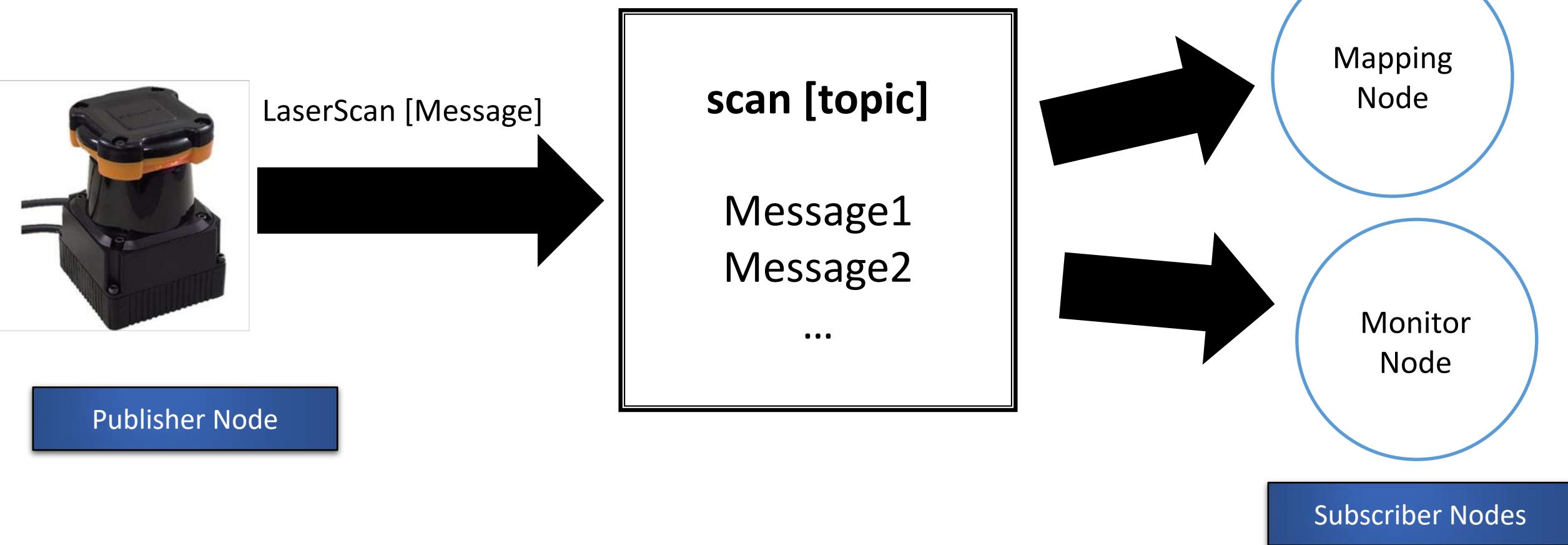
Publish a message to a topic

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



# Communication between nodes

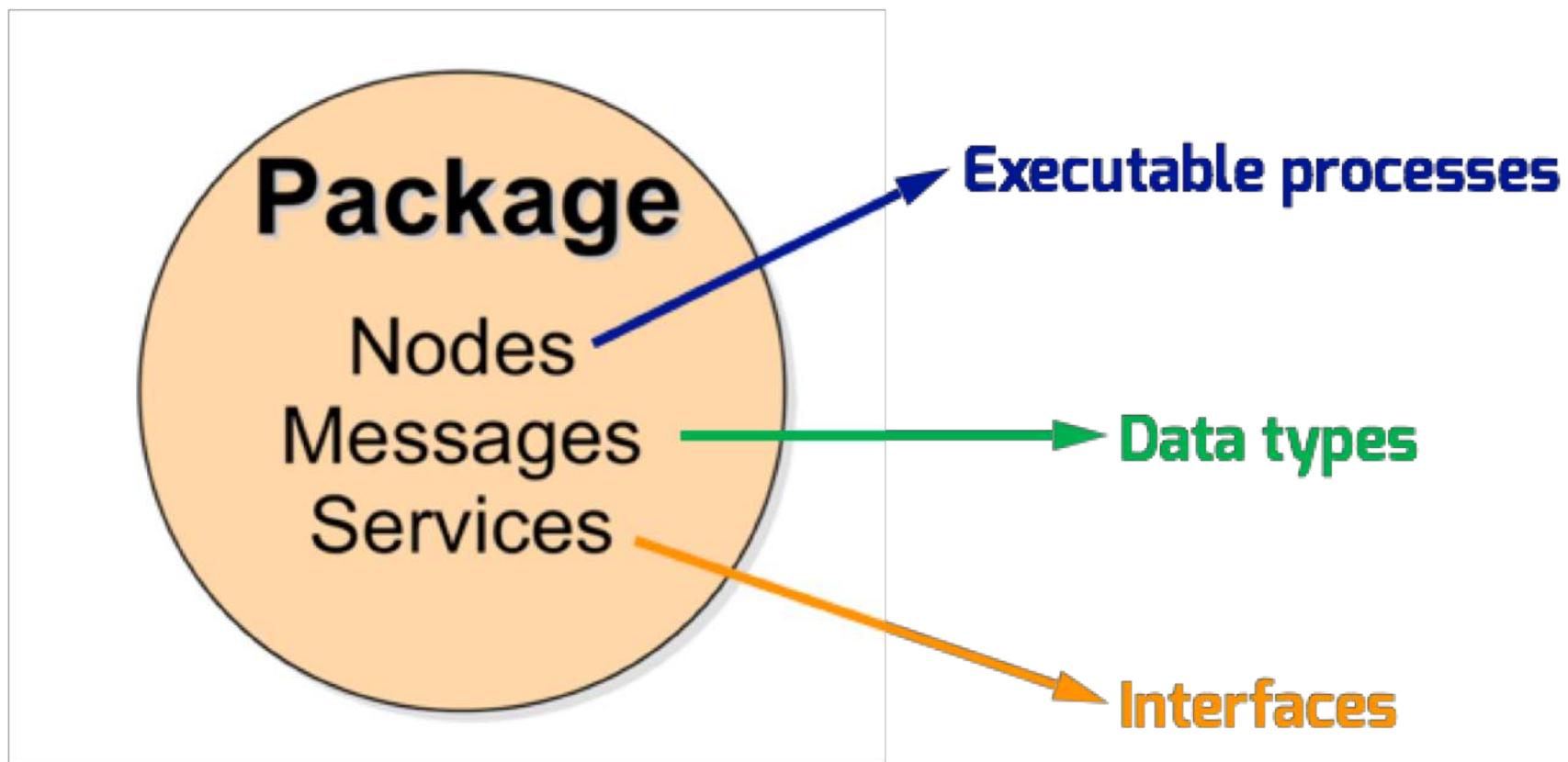
Nodes communicate **messages** via **topics**  
in an asynchronous publish-subscribe model



# ROS: Packages

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

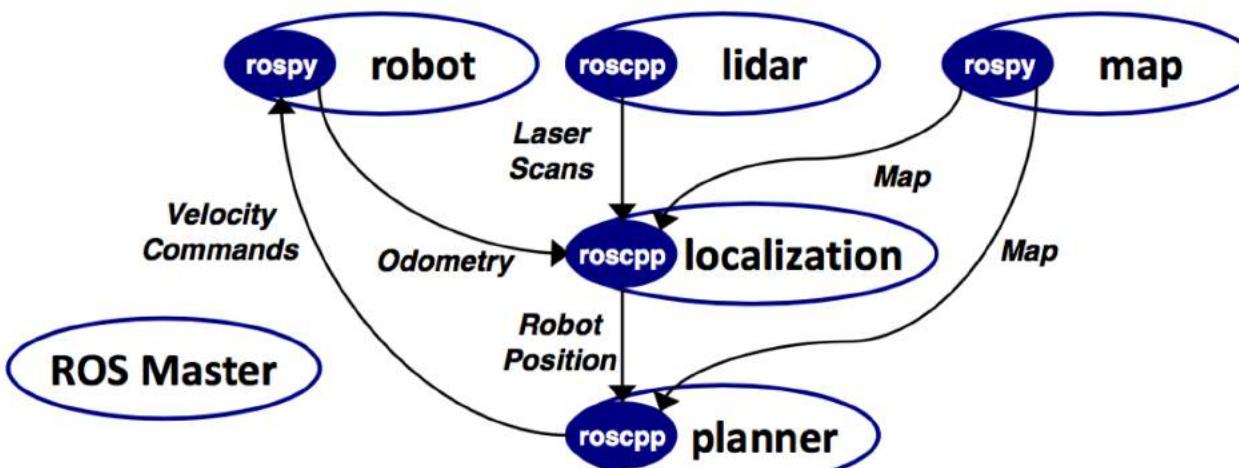
A **package** contains one or more **nodes**.



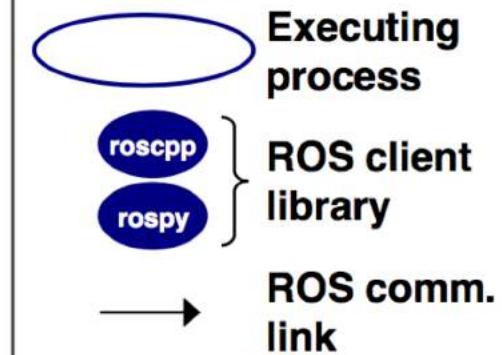
# ROS Computational Graph / Communication: Computational Graph

- 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):

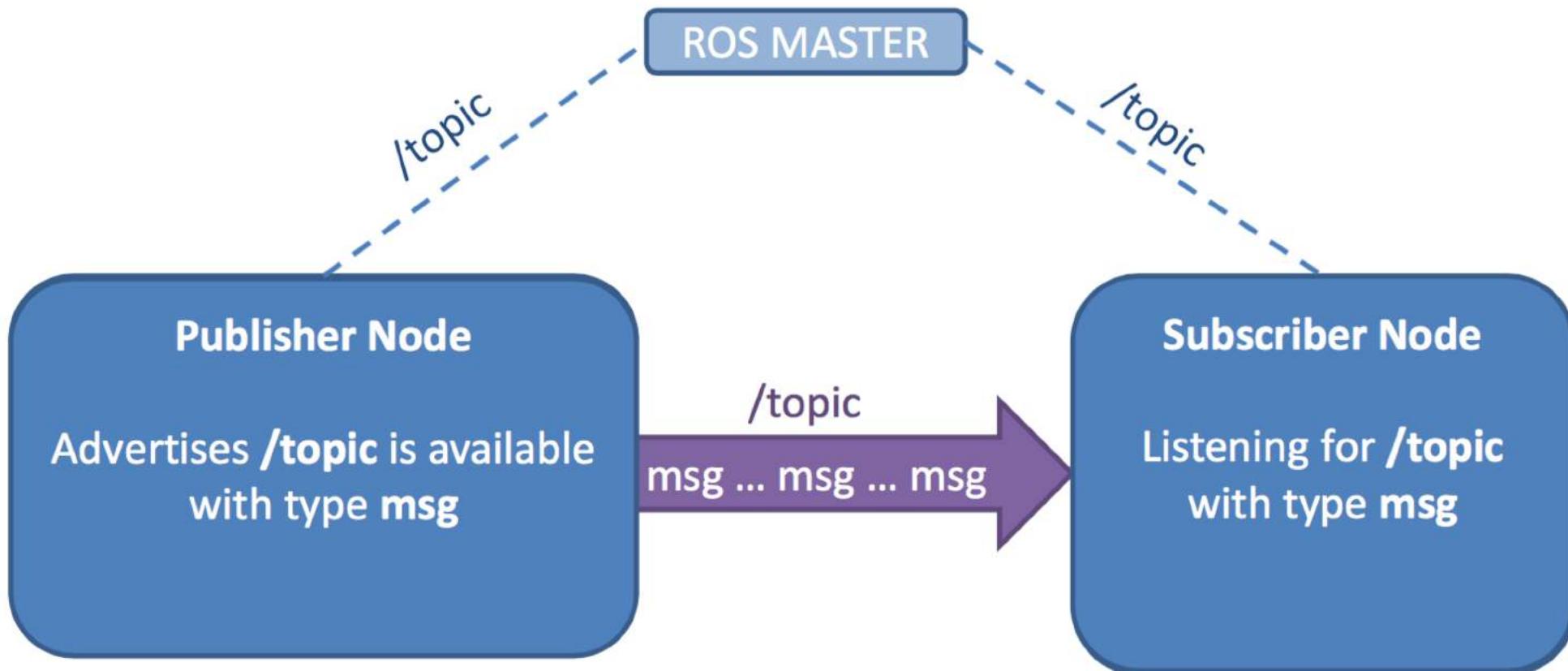


## Legend:



# 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

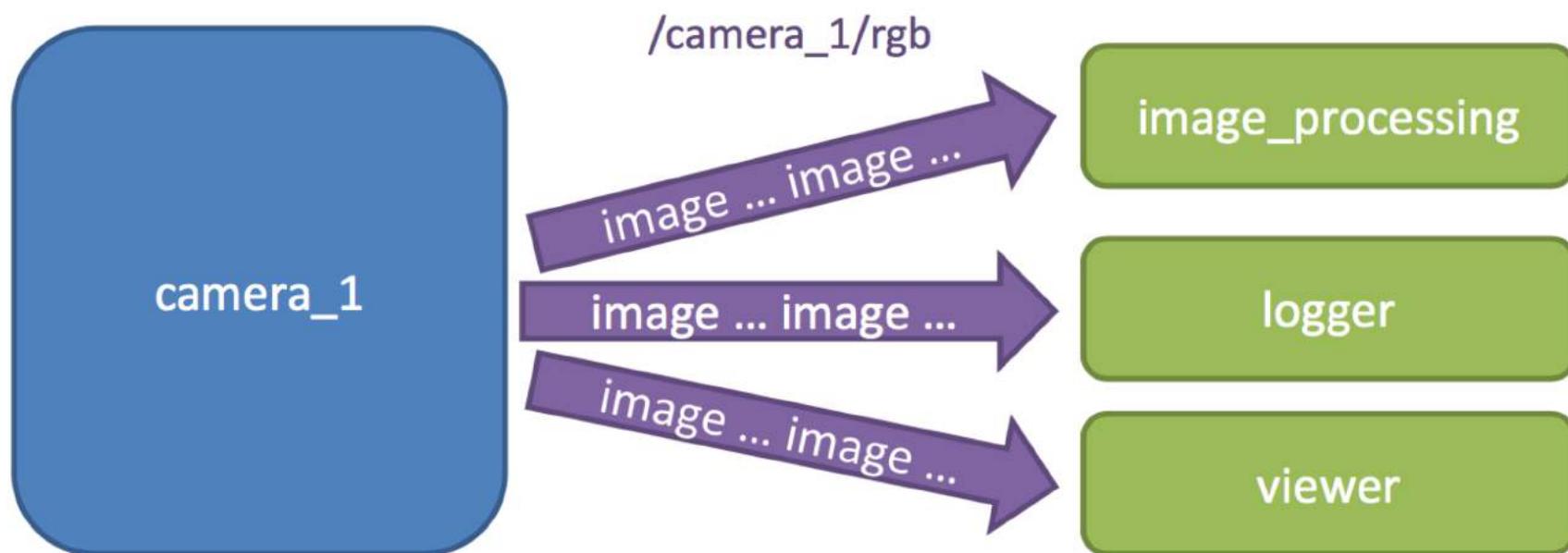
---

- 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

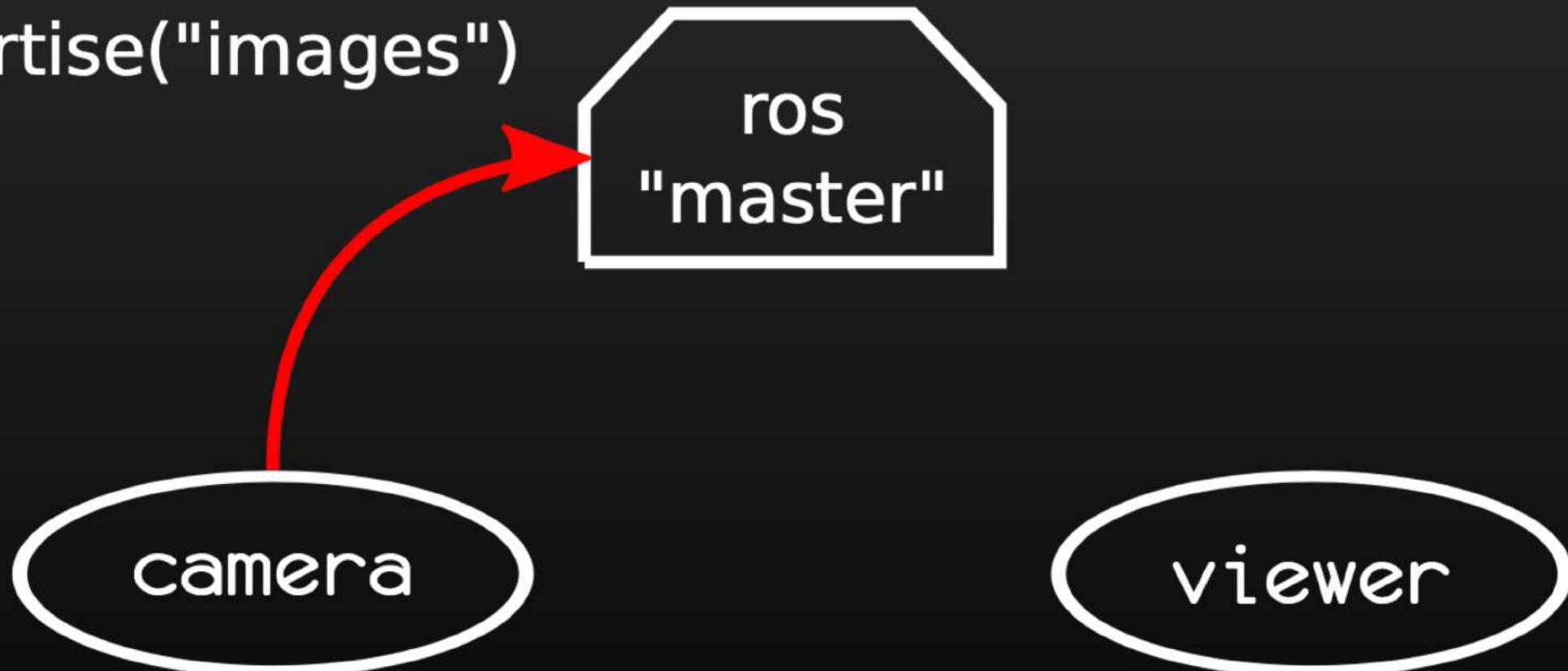


ros  
"master"

camera

viewer

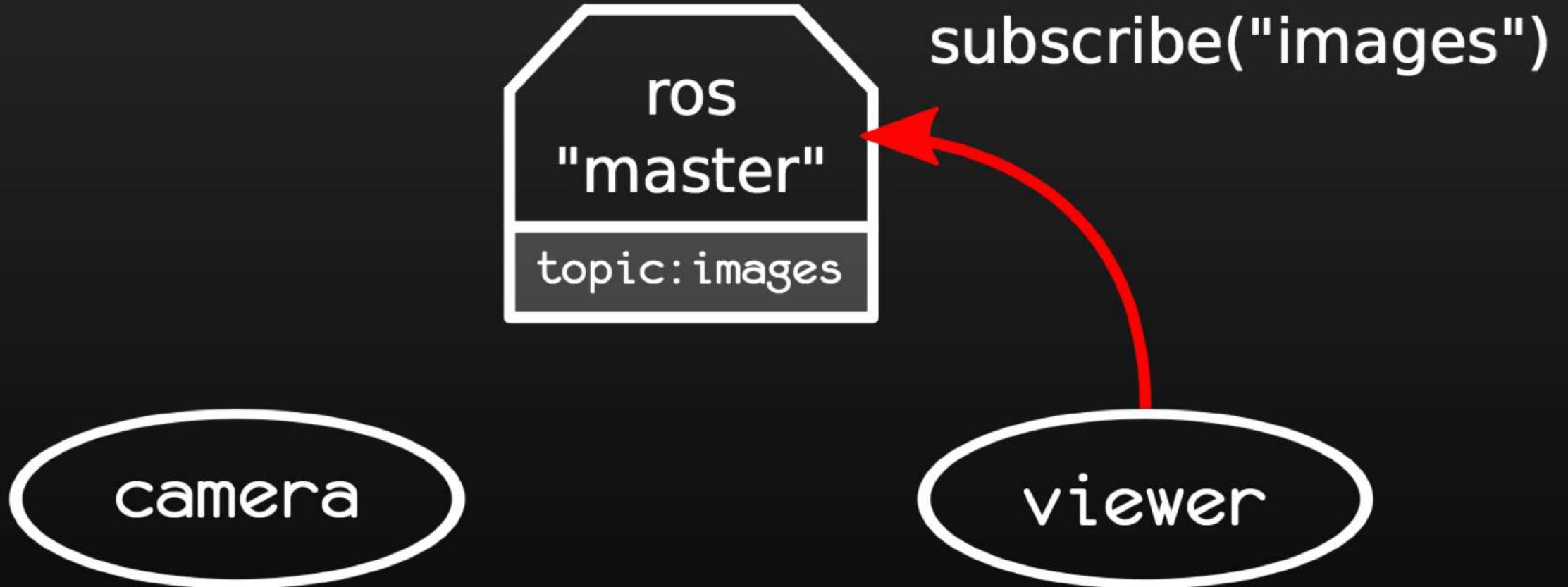
```
advertise("images")
```

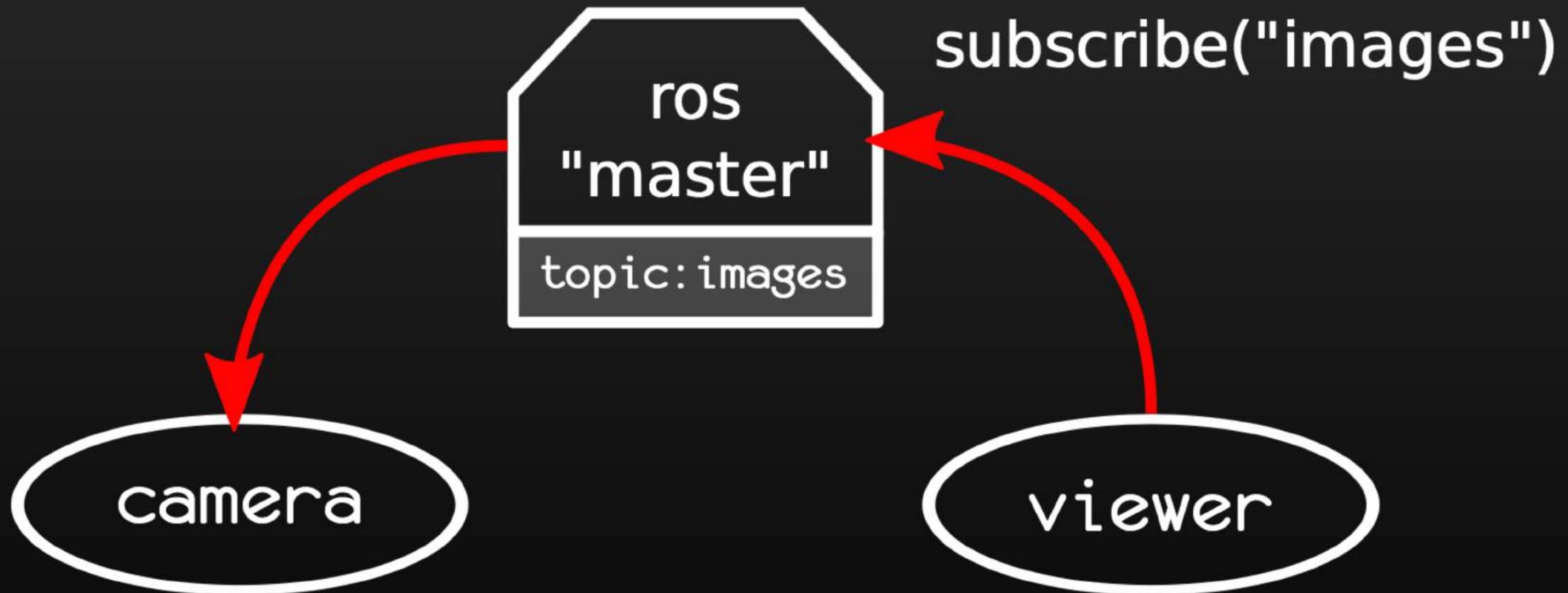


camera

ros  
"master"  
topic:images

viewer









images (tcp)

camera

viewer

publish(img)



images (tcp)

camera

viewer

publish(img)



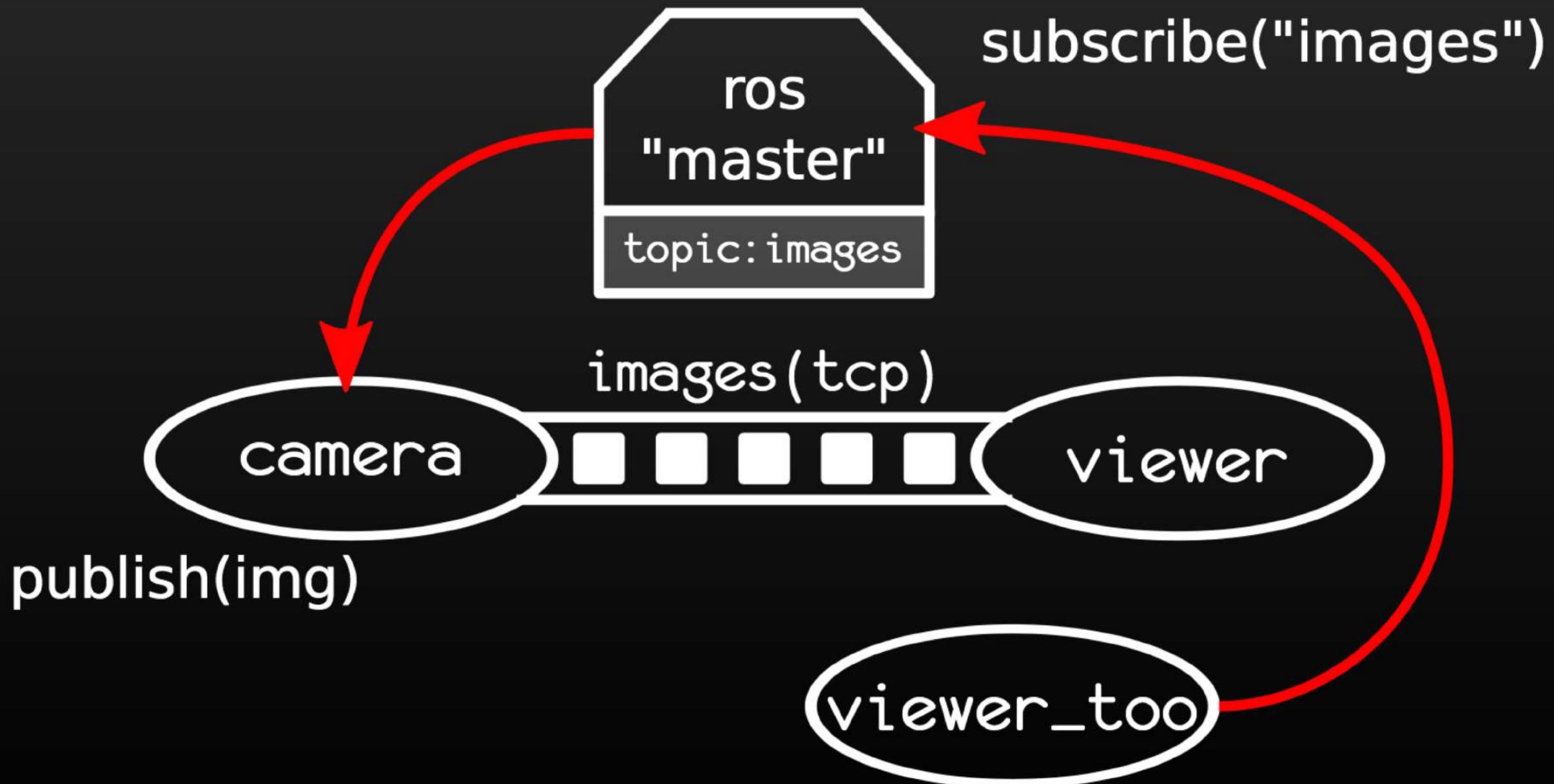
images (tcp)

camera

viewer

publish(img)

viewer\_too





images (tcp)



publish(img)

images (tcp)

viewer\_too

# 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
```



Publishes on topic: Scan

Scan [Topic] →

**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>	<b>Pharo Smalltalk</b>	
<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

**Live Demo**