Synthesis and Robotics

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Joint work (this talk) with: Jim Jing, Ben Johnson, Cameron Finucane, Nir Piterman and Vasu Raman
• “Drive around the city and obey traffic laws. Do not hurt anyone or anything”

• Teams of engineers from industry and academia and...
• “Go fetch me a beer”

Willow garage blog

• Week long hackathon at Willow Garage
Now

Specifications ("What")

Implementation ("How")

Testing ("Works?")

Control (probably works)
In the (near) future

Specifications ("What")

Automatic Correct-by-construction synthesis

Control (works!)
• **Patrol the aisles.**
• If you find a missing item, call the manager.
• Avoid aisles with spills.
Continuous task (motion and action of a robot)

Automatic
Provably correct

Sensing and Control for the robot
Continuous task (motion and action of a robot)

Discrete Abstraction

Discrete specification and model

Synthesize provably correct solution

Continuous implementation of solution

Sensing and Control for the robot
Continuous task (motion and action of a robot) → Reactive to the environment → Discrete Abstraction → Discrete specification and model → Synthesize provably correct solution → Continuous implementation of solution → Sensing and Control for the robot
Continuous task (motion and action of a robot)

Reactive to the environment

Discrete Abstraction

Sensor abstraction, atomic controllers

Discrete specification and model

Synthesize provably correct solution

Continuous implementation of solution

Sensing and Control for the robot
Continuous task (motion and action of a robot)

Reactive to the environment

Discrete Abstraction

Sensor abstraction, atomic controllers

Discrete specification and model

Linear Temporal Logic, (Structured) language

Synthesize provably correct solution

Continuous implementation of solution

Sensing and Control for the robot
Structured English Grammar

# Assumptions about the environment
If you were in porch then do not person
If you were in porch then do not hazardous_item

# Define when and how to pick up and drop
Do pick_up if and only if you are sensing hazardous_item and you are not activating carrying_item
Do drop if and only if you are activating carrying_item and you were in porch

# Define when and how to radio
Do radio if and only if you are sensing person
If you are activating radio or you activated radio then stay there

# Patrol goals
If you are not activating carrying_item and you are not activating radio then visit dining

If you are activating carrying_item and you are not activating radio then visit porch
Continuous task (motion and action of a robot)

Reactive to the environment

Discrete Abstraction

Sensor abstraction, atomic controllers

Discrete specification and model

Linear Temporal Logic, (Structured) language

Synthesize provably correct solution

LTL synthesis, probabilistic model checking

Continuous implementation of solution

Hybrid controller

Sensing and Control for the robot
(Partial) Related work

- Robot Control from Temporal Logic specifications: Kavraki and Vardi, Belta, Karaman and frazzoli, Fainekos, Wongpiromsarm Topcu and Murray, ...

- Symbolic control, languages and grammars for control: Egerstedt, Frazzoli and Dahleleh, Klavins, Stilman, Tanner, ...

- Hybrid systems
- Formal methods - synthesis
- Planning community
Human controlling a robot

- **Patrol the aisles.**

  group Corners is r1, r2, r3, r4
  if you are not activating call_manager then visit all Corners
  do look_leftright if and only if
    you are not activating call_manager and
    you were in (between r1 and r2 or between r3 and r4)

- **If you find a missing item, call the manager.**

  call_manager is set on see_missingitem and reset on head_tapped
  if you are activating call_manager then stay there

- **Avoid aisles with spills.**

  spill_top is set on (r1 or r2) and see_spill and reset on false
  spill_bottom is set on (r3 or r4) and see_spill and reset on false

  if you are activating spill_top then always not between r1 and r2
  if you are activating spill_bottom then always not between r3 and r4
Human controlling a robot

• Specification Unsatisfiable:

\[ \neg \varphi_s \]

“Start in Deck. Always stay there. go to kitchen. ”

• Specification Unrealizable:

\[ \exists \text{Environment} \models \varphi_e \quad \text{s.t.} \quad \neg \varphi_s \]

“Start in Deck. If you see a person stay there. go to kitchen. ”

• Trivial solution:

\[ \forall \text{Robot} \models \varphi_e \rightarrow \varphi_s \]

“Always person and not person. ”
Human controlling a robot

Robot starts with false
Robot starts in deck
Visit porch
If you are sensing person then do not kitchen
If you are sensing fire then do not living
Always do not (fire and person)
Always do not radio

Raman and KG: CAV 2011, ICRA 2012, IEEE TRO
Human controlling a robot

Robot starts with false
Robot starts in *deck*
Visit *porch*
If you are sensing *person* then do not *kitchen*
If you are sensing *fire* then do not *living*
Always do not (*fire* and *person*)
Always do not *radio*
Human controlling a robot

High-Level Tasks → Environment Model → Robot Abstraction

Correct Controller

? → Imperfect Sensors → Environment
Human controlling a robot

Controller Synthesis

$\Phi$ $X$ $Y$

$R$ s.t. $E \parallel R \models \Phi$

DTMC Construction

$E, \bar{E}$

Probabilistic Model Checker

$\Phi$

$P( E \parallel \bar{R} \models \Phi )$

Johnson and KG, RSS 2011, Johnson, Havlak, Campbell and KG, ICRA 2012
Human controlling a robot

Obstacle Location at time = $t$

Possible Robot State at time = $t+3s$

Obstacle Predicted at time = $t+3s$

Robot Location at time = $t$

Johnson and KG, RSS 2011, Johnson, Havlak, Campbell and KG, ICRA 2012
Human controlling a robot

Johnson and KG, RSS 2011, Johnson, Havlak, Campbell and KG, ICRA 2012
Human controlling a robot

\( \varphi_{r_1} \land \neg \pi_{camera} \)
(Robot starts in region r1 with the camera off)

\( \land \Box (\bigcirc \pi_{camera} \iff \bigcirc \pi_{person}) \)
(Activate the camera if and only if you see a person)

\( \land \Box \Diamond (\pi_{r_2}) \)
(Go to r2 infinitely often)
Human controlling a robot

\[ \varphi_{r_1} \land \neg \pi_{\text{camera}} \]
(Robot starts in region r1 with the camera off)

\[ \land \Box (\Box \pi_{\text{camera}} \Leftrightarrow \Box \pi_{\text{person}}) \]
(Activate the camera if and only if you see a person)

\[ \land \Box \Diamond (\pi_{r_2}) \]
(Go to r2 infinitely often)
Human controlling a robot

Option 1: Actions end together

Raman, Finucane and KG, IROS 2012, Raman, Piterman and KG, ICRA 2013 (To appear)
Human controlling a robot

Option 2: Actions **start** together

Raman, Finucane and KG, IROS 2012
Human controlling a robot

Option 3: Model activation and completion of Actions

\[ \varphi_{fair}^a = \Box \Diamond (\varphi_a^{completion} \lor \varphi_a^{change}) \]
LTLMoP

• Linear Temporal Logic MissiOn Planner
• Use structured English to control a robot
• Python-based
• Modular
• Integrates with simulators (Gazebo) and physical robots

http://ltlmop.github.com/
Robot waiter scenario - hot off the press