Semantic Place Classification for Autonomous Agricultural Robots

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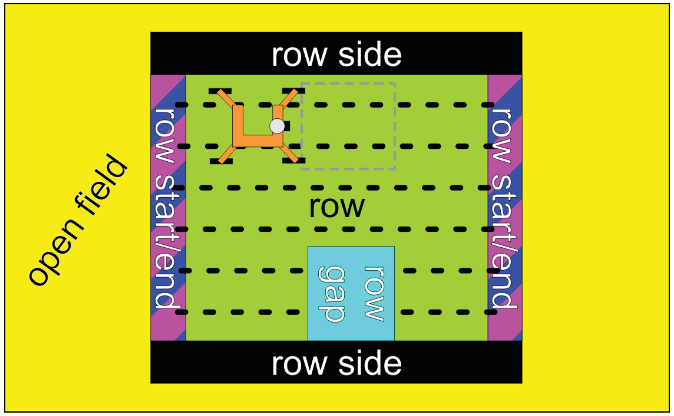

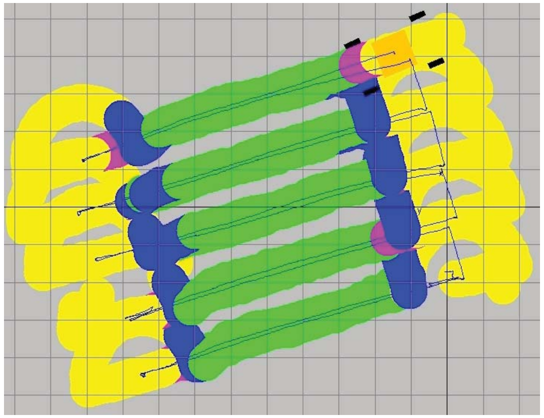

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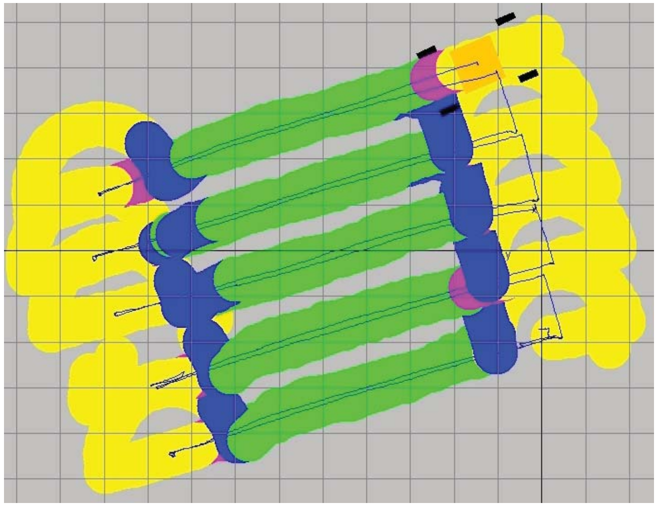
Overview

- Background and Motivation
- Semantic Place Classification
- Experiments
- Future Work



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Background and Motivation

- State of the art in automatic guidance of agricultural machinery
  - Highly precise but expensive GPS devices for navigation
  - Guidance of huge machinery
  - Need to teach vehicle to field
  - Suitable for plowing, seeding and harvesting
  - Not suitable for individual plant treatment and fully autonomous navigation

Source: http://www.deere.com

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Background and Motivation

Background and Motivation

- Our focus
  - Autonomous navigation of “small” agricultural vehicles
  - Individual plant treatment
    - Conduct the right treatment, at the right place and at the right time
      - Selective phenotyping
      - Selective crop harvesting
      - Selective spraying
      - Selective fertilization
      - Selective weeding

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- ➔ Our focus
  - Autonomous navigation of "small" agricultural vehicles
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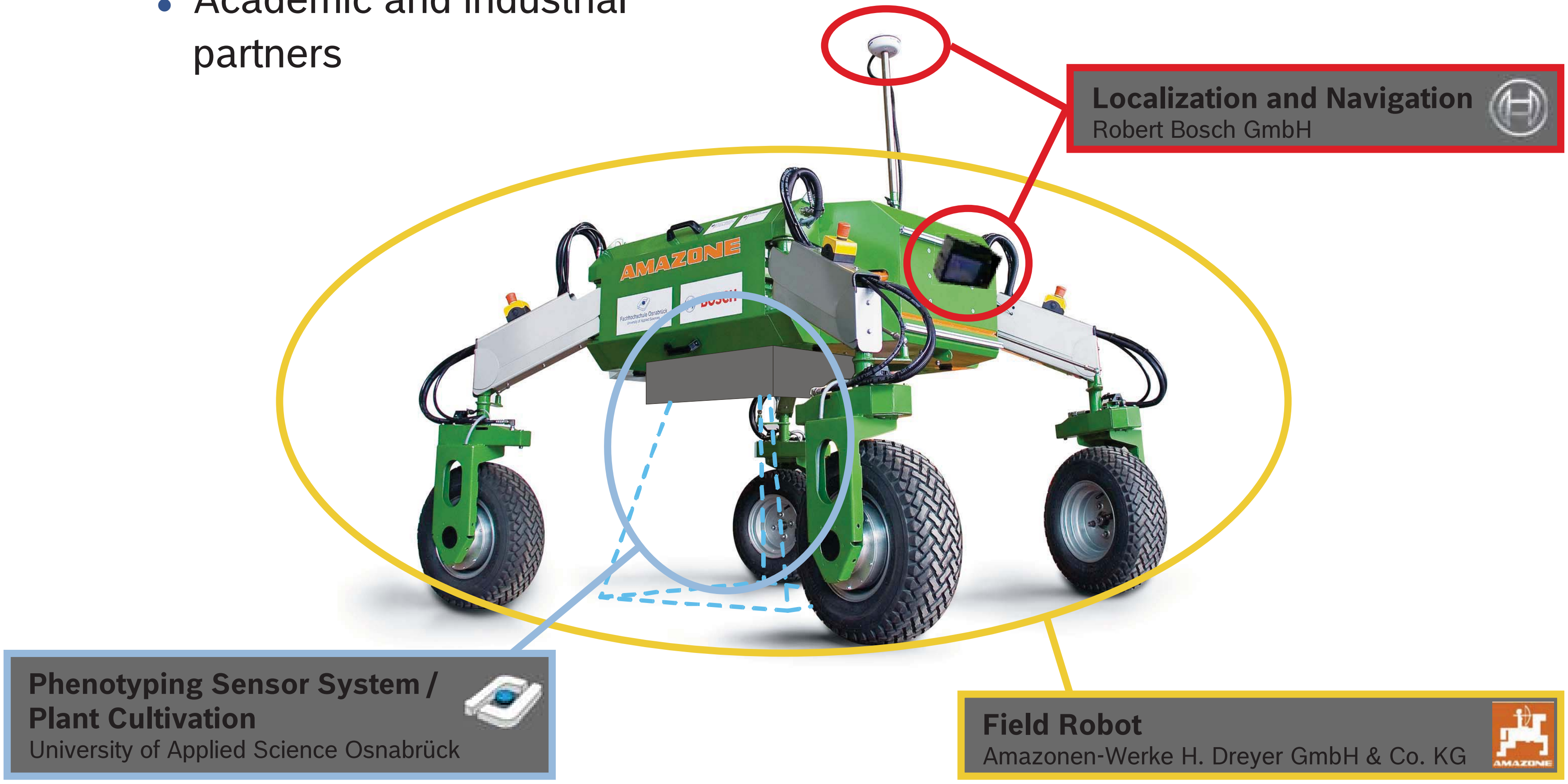
    - Conduct the right treatment, at the right place and at the right time
      - Selective phenotyping
      - Selective crop harvesting
      - Selective spraying
      - Selective fertilization
      - Selective weeding
    - Reduction of fertilizers and pesticides
    - Increase crop yield
  - Need for
    - Automation
    - Environment sensing

Background and Motivation

- BoniRob Project (funded by the German Agricultural Ministry)
  - Autonomous crop scout for individual plant phenotyping
  - Academic and industrial partners



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Background and Motivation

- BoniRob use case
  - Row cultivations
  - Previously unknown fields
- Sensors for Navigation
  - No expensive GPS device
  - 3D lidar sensor
- Localization of the robot
  - Metric localization
  - According to its environment
    - Semantic place classification
    - Partition field into semantic classes of places
    - Probabilistic approach

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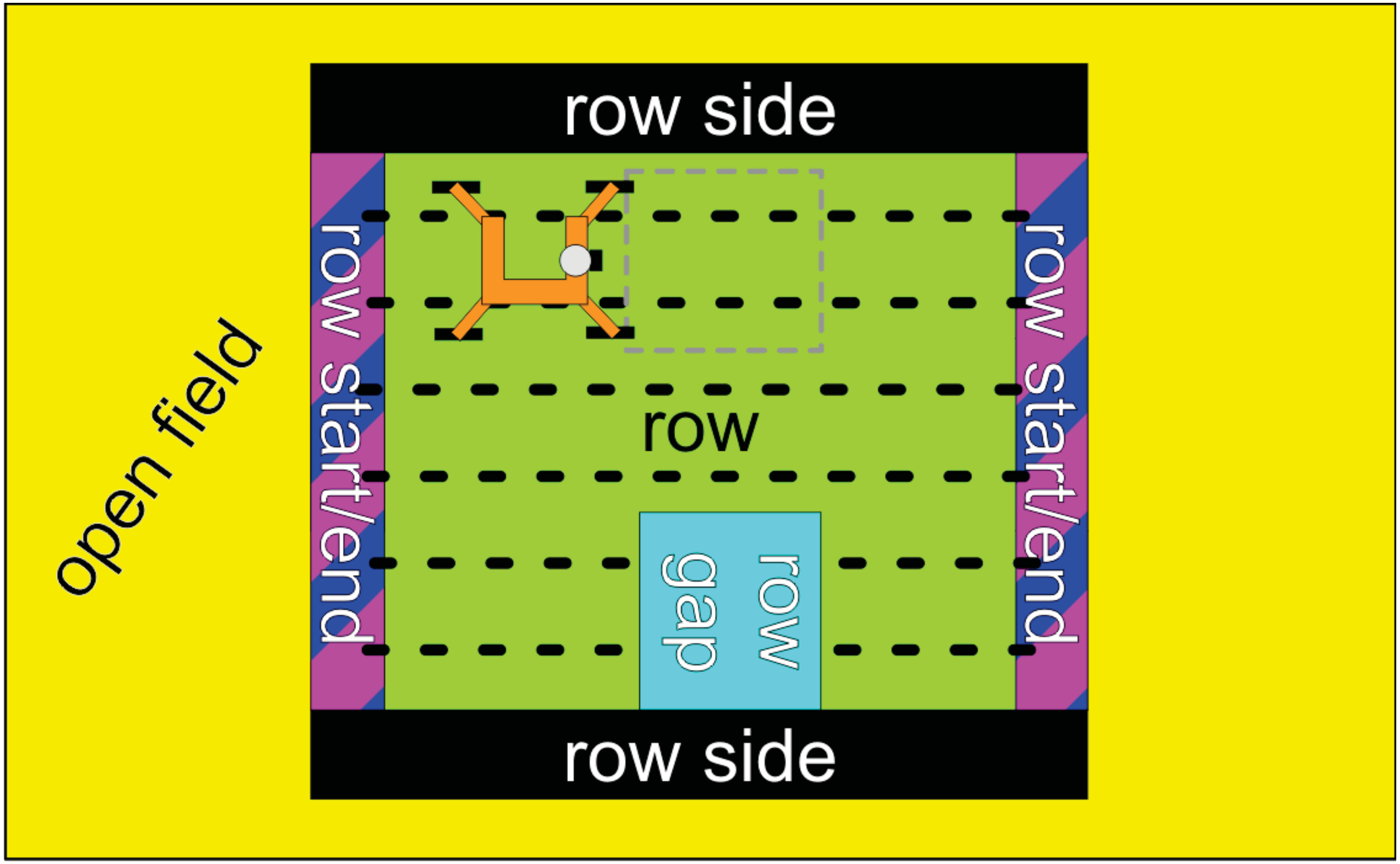
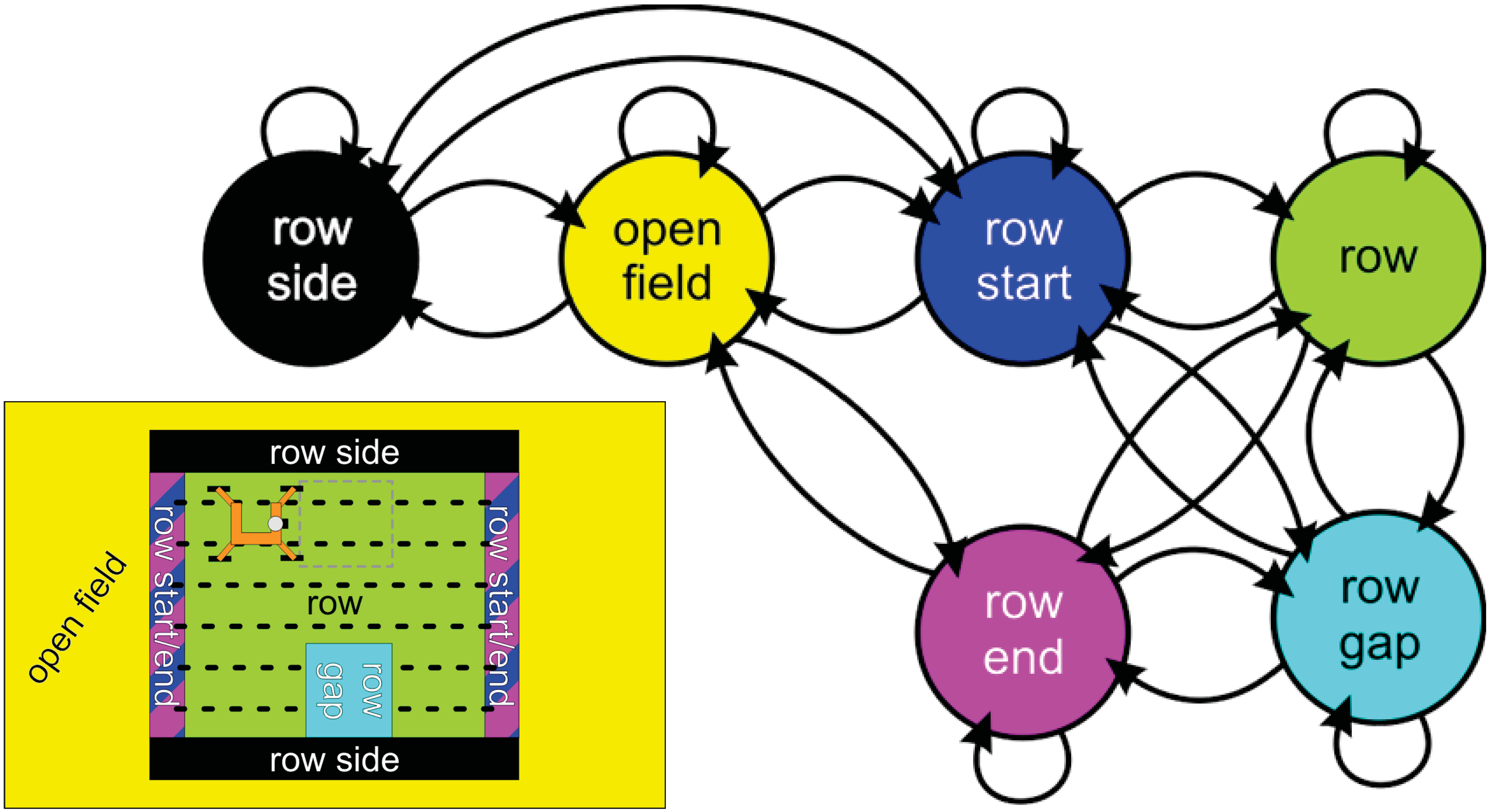
Semantic Place Classification : Partitioning

- Place partitioning



Semantic Place Classification : Partitioning

- Transitions between the places



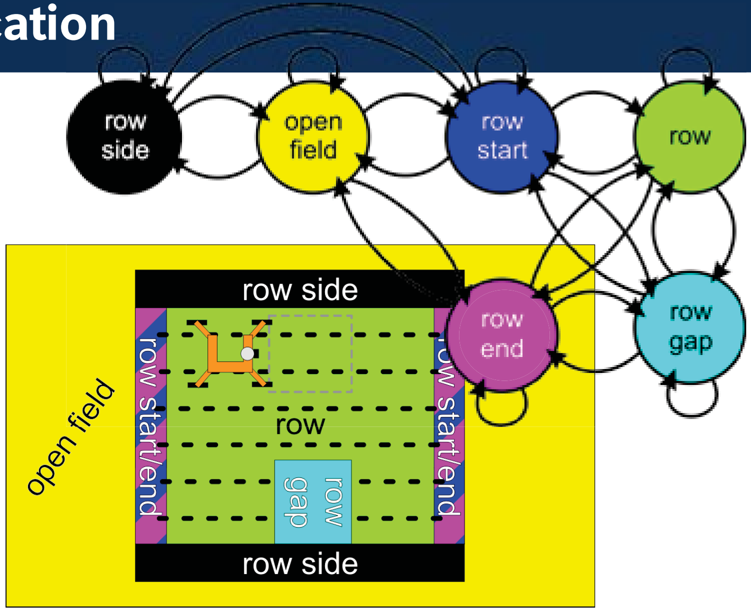
Semantic Place Classification : Classification

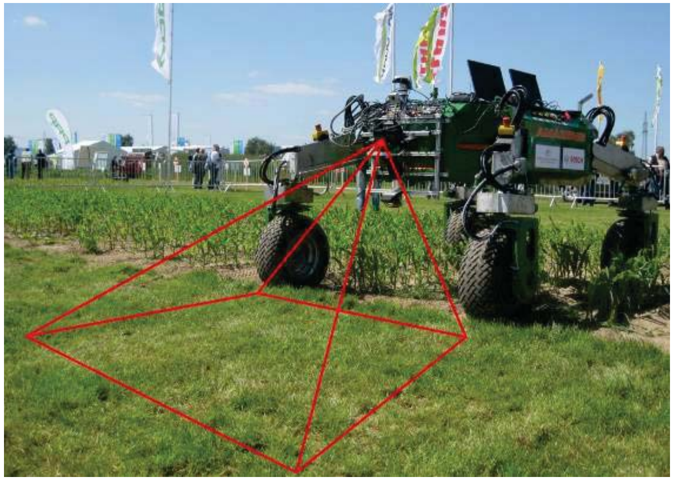
→ Applications

- Navigation commands
- Monitor execution of the navigation
- Improve metric localization

→ Place classification

- Calculate probability over all states
- Transport probabilities using the automaton
- Reweight the probabilities using sensor measurements
- Use further state independent information





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Semantic Place Classification : Classification

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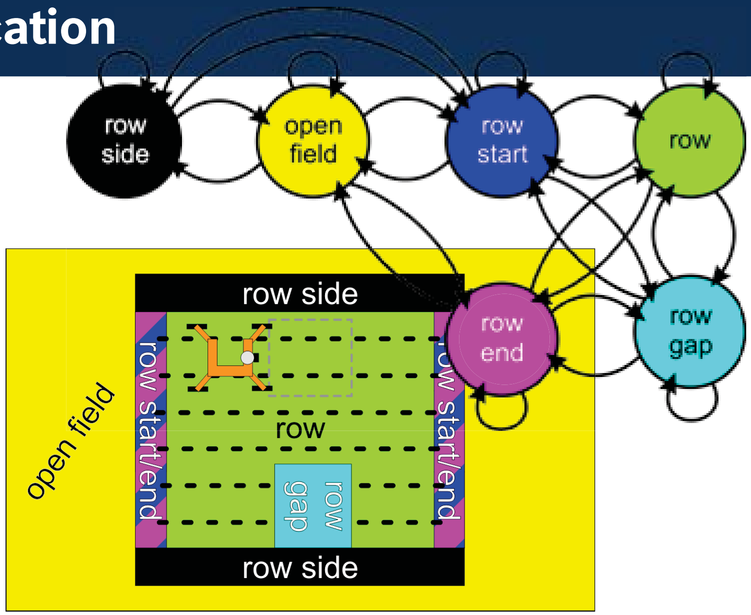
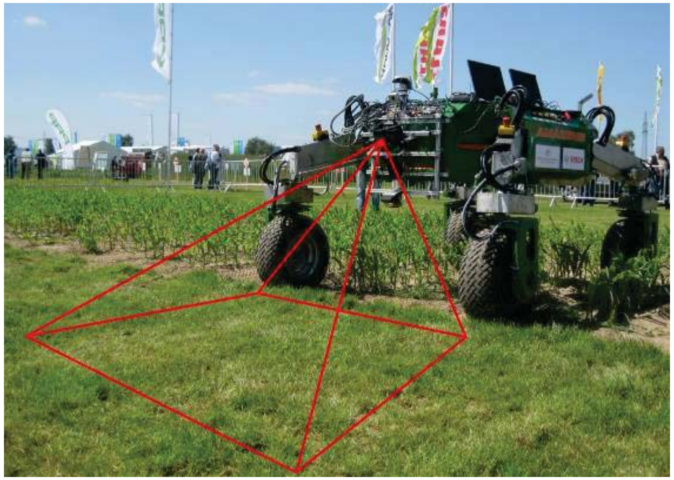
=> Particle filter





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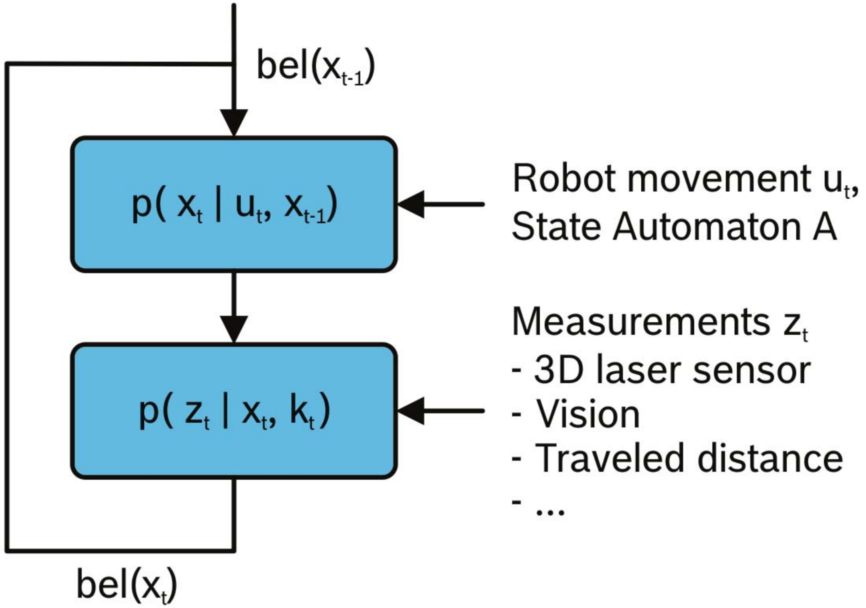
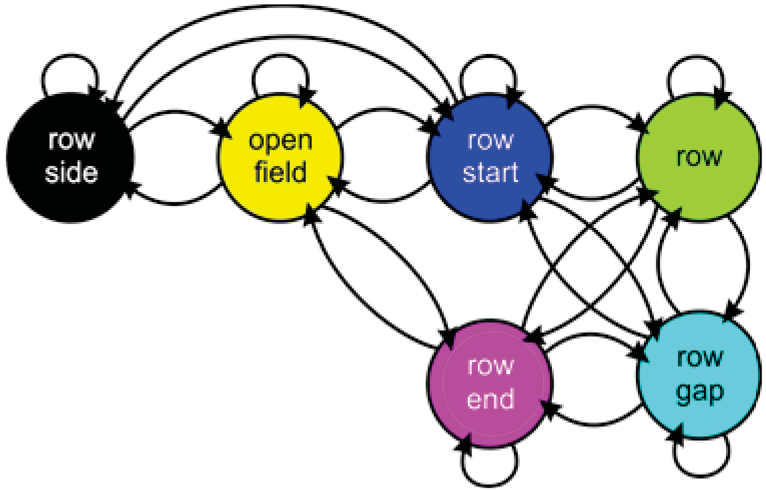
Semantic Place Classification : Classification

- Particle filter
  - Particles $\mathbf{x_t}$:
    - State id
    - Importance factor
    - Additional information
      - Traveled distance
      - Turned angle
      - ...
  - Sampling $\mathbf{p(\, x_t \mid u_t, x_{t-1})}$
    - State transition using robot movement $\mathbf{u_t}$ and state automaton
  - Measurement $\mathbf{p(\, z_t \mid x_t, k_t\,)}$
    - Reweight probabilities using sensor measurements $\mathbf{z_t}$ and knowledge $\mathbf{k_t}$

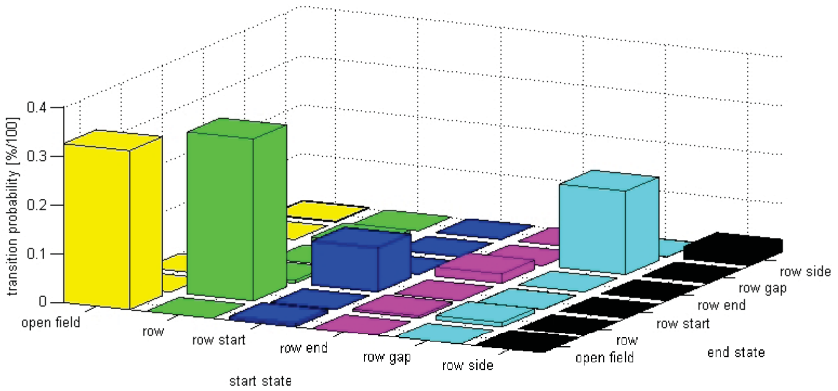


Semantic Place Classification : Classification

- Sampling: $\mathbf{p(x_t \mid u_t, x_{t-1})}$
  - Transport particles using the state automaton and the robot movement $\mathbf{u_t}$
    => calculate new **state id**
  - Transition probabilities for different movements:
    - Robot stays: $\mathbf{A_{stay}}$
    - Robot moves: $\mathbf{A_{move}}$
  - Experimentally determined probabilities



Transition probabilities for automaton $\mathbf{A_{move}}$



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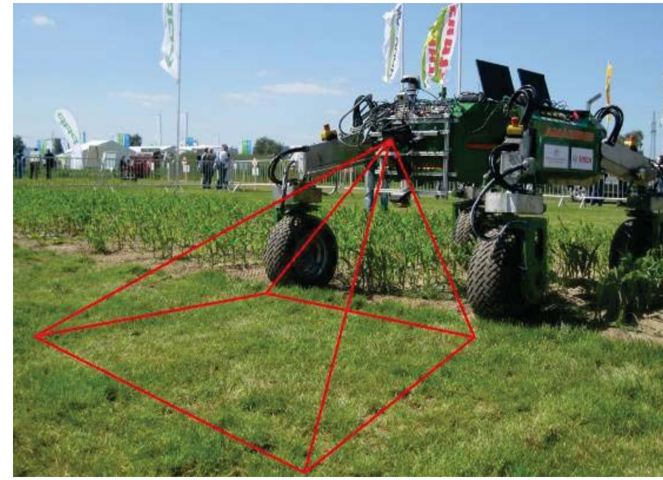
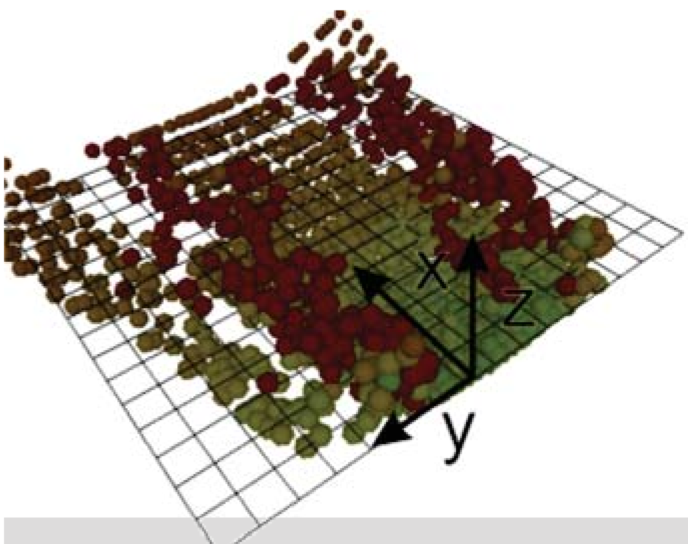
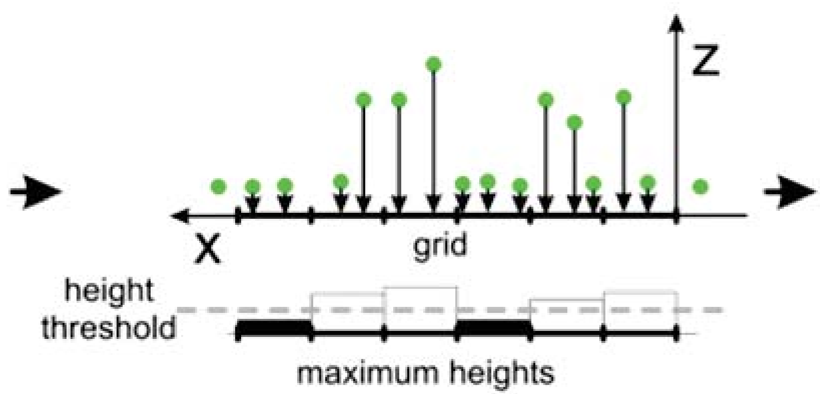
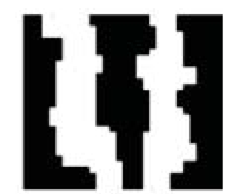
Semantic Place Classification : Classification

- Measurement: $\mathbf{p(z_t \mid x_t)}$
  - Calculate probability of measurement depending on the **state id**
  - Currently usage of 3D lidar sensor
    - Sensing ground ahead of robot
    - Low resolution (59x29 rays)
    - Determine simple patterns and compare them with expected patterns



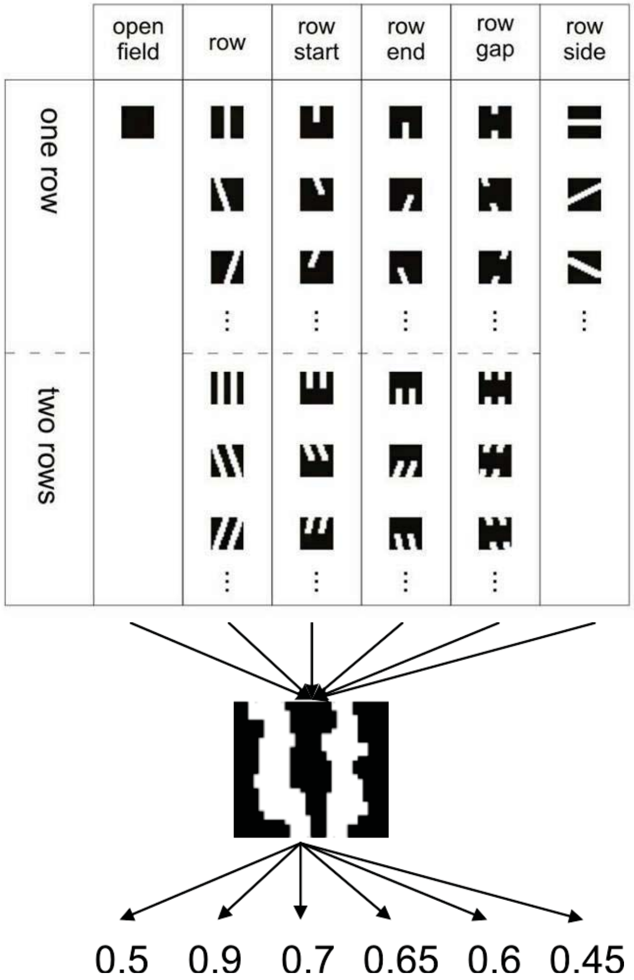






Semantic Place Classification : Classification

- Pattern matching
  - Pattern database
    - Defines several pattern for each class
    - Application specific
      - One or two rows
      - Row displacement
    - Easily exchangeable
  - Probability calculation
    - Compare detected pattern with whole database
    - Calculation of correlation (normalized SSD)
    - Probability = Maximum correlation for each class



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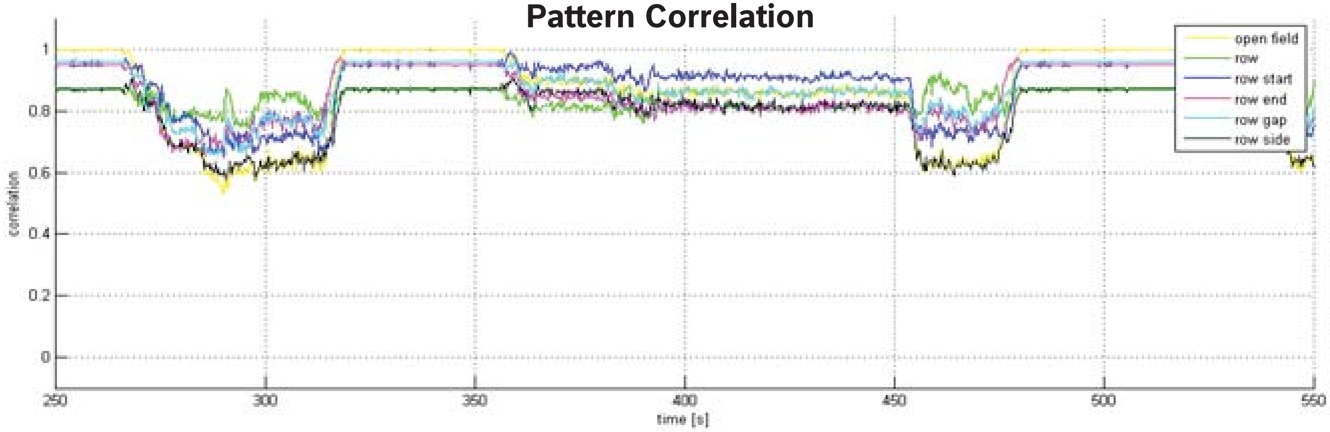
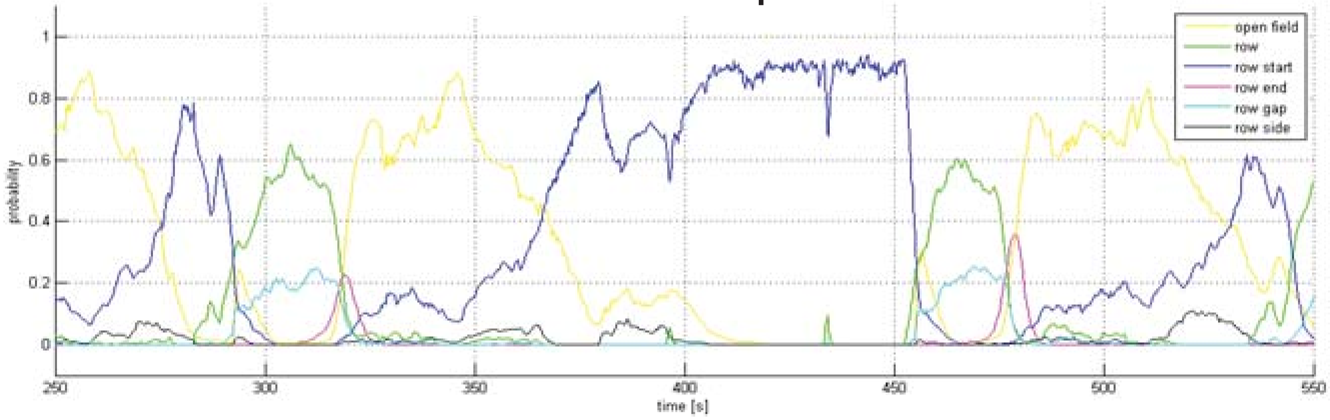
Semantic Place Classification : Classification

- Pattern matching

Pattern Correlation

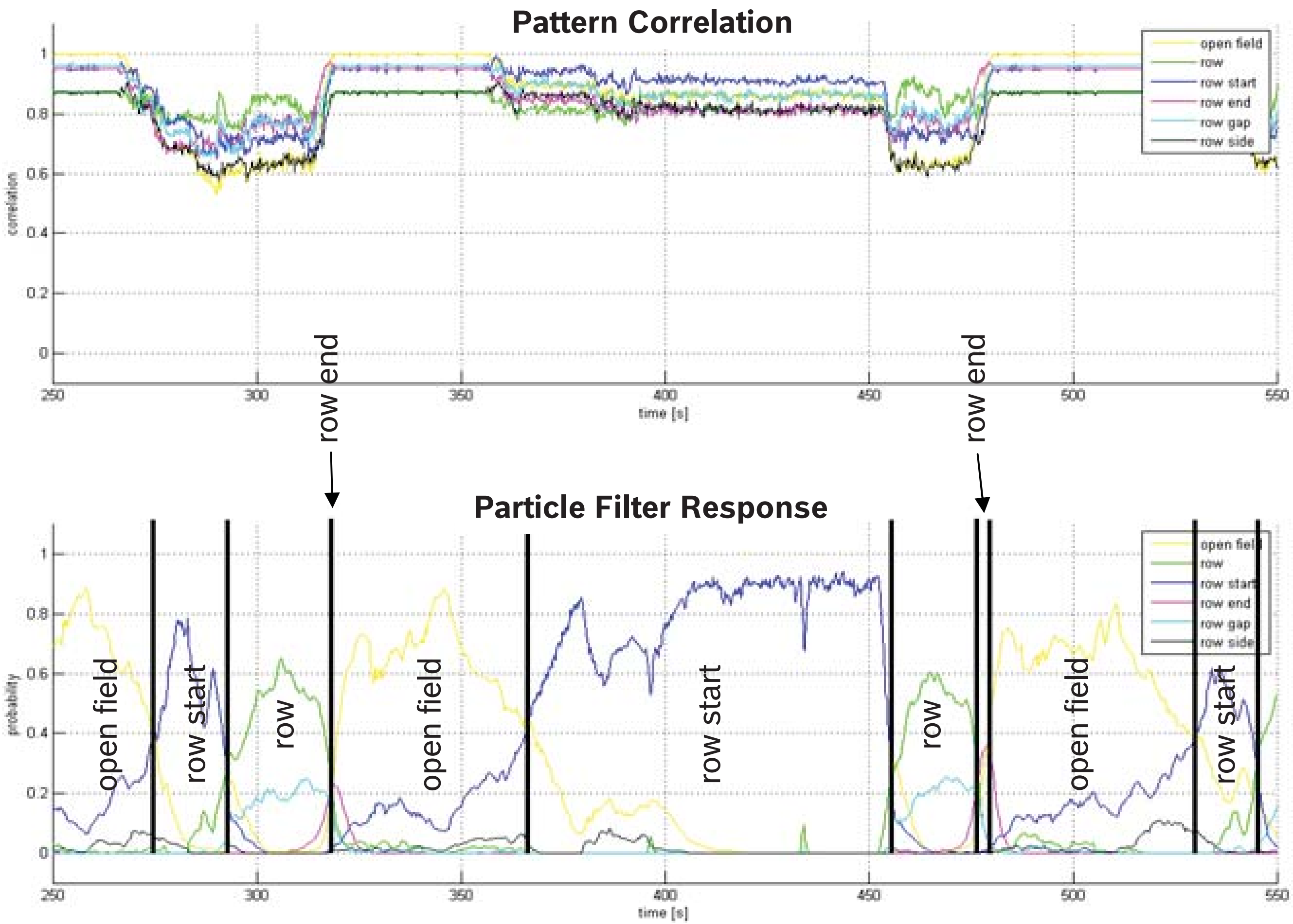


Particle Filter Response



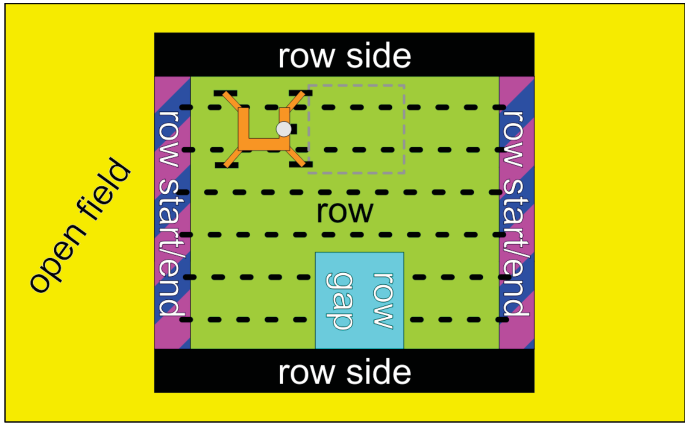
Semantic Place Classification : Classification

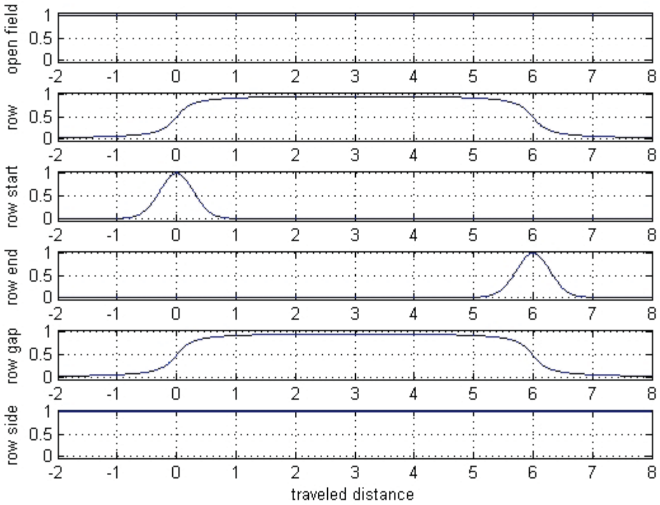
➔ Pattern matching



Semantic Place Classification : Classification

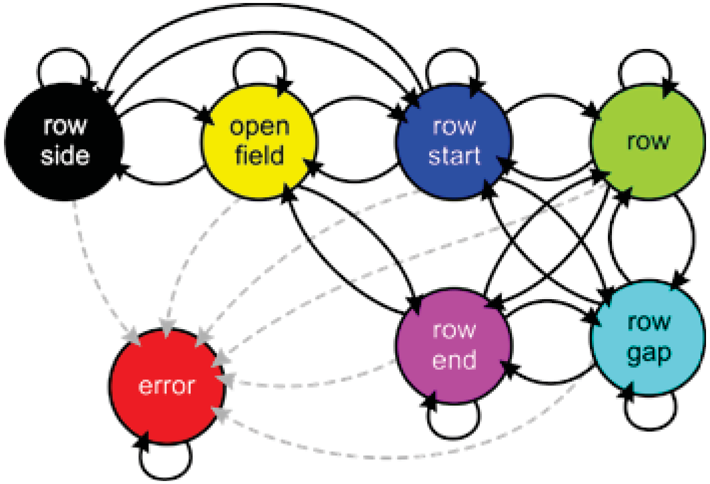
- Measurement: $\mathbf{p(z_t \mid x_t, k_t)}$
  - Calculate probability of measurement depending on the **state id** and additional knowledge $\mathbf{k_t}$
  - $\mathbf{k_t}$: row length, turn angle, field borders, ...
  - Use knowledge about estimated row length
    - Distinguish **row end** and **start** from **row gap**
    - Add traveled distance variable to particles
    - Cumulate the traveled distance in **row** and **row gap** state
    - Reset traveled distance on **open field**
    - Calculate measurement probabilities using state specific functions





Semantic Place Classification : Error Detection

- Deal with not predictable situations
- Improvement of robustness and safety
- Possible errors
  - Obstacles like persons
  - A turn in the row state
  - Wrong row displacement
  - Not allowed transition
- Add error state to automata
  - Connect each state with **error** state
  - Sampling step: Fixed probability to end in the **error** state
  - Measurement: Fixed correlation value



Experiments

- Experimental setup
  - Real and simulated Robot
  - Ground truth localization using RTK-GPS, IMU and Odometry
  - Test fields with different complexities
    - Plant height: 0.1 – 1.5 m
    - Row length: 5 – 40 m
    - Gap probability
    - Weed density

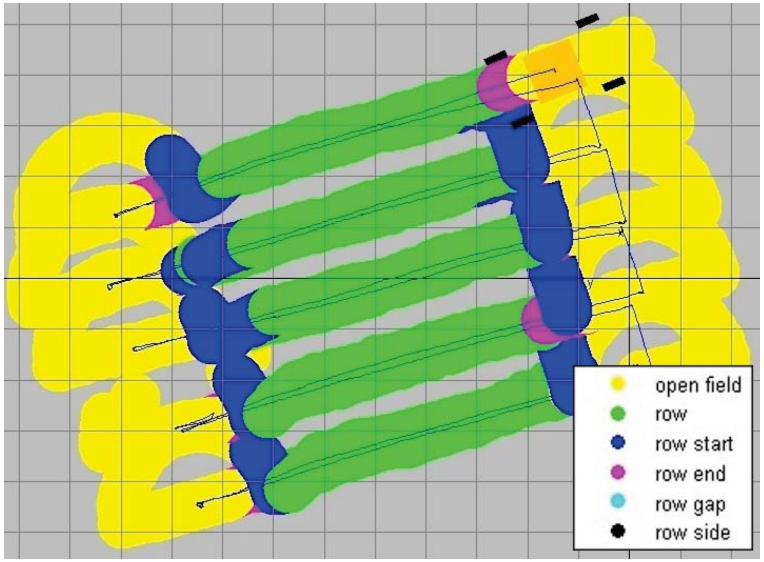
Experiments

➔ Results

- Video

- Classification rates
  - Similar results for simulation and real field experiments
  - Around 96 % in average
  - Nearly 100% for state sequence

- Error detection
  - Error state is repeatedly reached in error situations
  - More evaluations have to be done



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Future Work

- Do more analysis for error detection
- Use additional sensor data and knowledge
  - Vision
  - Low resolution GPS and field borders
- Use semantic classification to improve metric localization
- Adjust transition probabilities online
- Distinguish between more different state automata


Thank you
for your attention!