Programming Reactive Probabilistic Applications

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Reactive Probabilistic Programming

Synchronous data-flow languages and block diagrams
- State of the art model for embedded systems
- E.g., Melanço/Simulink, SCADe, Lustre, Zillix
- Signal: stream of values; System: stream processor

ProbData: add support to deal with uncertainty
- Extend Data with probabilistic constructs
- Parallel composition: deterministic/probabilistic
- Inference-in-the-loop
- Inference on streams

Example: Robot

Goal: control robot's position using a noisy accelerometer and intermittent GPS
- Feedback between deterministic controller and probabilistic tracker

let node robot (acc, gps) = x where
  rec u = controller (gps, acc) and
  x_dist = infer tracker (u, acc, gps)

Probabilistic Programming

x = sample(d): introduce a random variable x of distribution d
observe(x, y): condition the fact that x was sampled from d
infer a obs: compute the distribution of output of the model with respect to obs

Evaluation

Language features:
- Moving parameters
- Fixed parameters
- Inference-in-the-loop

Algorithm comparison
- PF: Particle Filtering
- SDS: Streaming Delayed Sampling

Example: SLAM

Simultaneous Localization And Mapping
- Environment: slippery wheels and noisy sensor
- System: infer current position and map, output command (left/right/up/down)

let state = pos, rot
let next [[model]] (state, command) = (next_pos, next_rot)

let infer position = infer sensor (observed value of a map cell)
let estimated position = compute estimated position

At each step:
- Move to the next position
- Observe the color of the ground
- Use inferred position to compute next command

Evaluation

Baseline: SDS with 1,000 particles
- PF: Particle Filtering
- SDS: Streaming Delayed Sampling
- Conclusion:
  - SDS is always faster but less accurate
  - Reduction in parallel count outweighs symbolic overhead
  - SDS can be exact (1 particle)
  - PF is impractical for advanced examples