Representing Swarm Behaviors

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The Context
Swarm Applications are distributed across a collection of diverse computational devices. Many of these devices are sensors, embedded systems, and mobile entities.
Swarm Applications: Features

- Concurrent Execution
- Message Sending
- Dynamic Configurability
- Dynamic Process Creation
- Code Mobility
- Semantic Heterogeneity
Swarm Processes

Swarm Processes are collections of behaviors that describe what happens in a Swarm Application.
Swarm Processes

Questions:

- How do we describe these processes?
- How do we deal with complex features such as code mobility and topological dynamicity?
- How do we deal with heterogeneity?
- How do we specify, verify, and synthesize?
- What is the logic of these processes?
What will this consist of?

- A representation/model for behaviors.
- A formal description of swarm processes in terms of these behaviors.
- A language to describe swarm applications.
- A formal semantics connecting this language to swarm process representations.
- An assertional language that forms observational atomic propositions about swarm processes.
- A logic language (with quantifiers, like LTL) to formulate swarm application requirements/contracts.
- Verification/synthesis tools.
Example: Home Automation
Registering a Device
Registering a Device

Diagram:
- Discovery
- Temp Sensor
- Query Manager

Connections:
- Discovery to Temp Sensor
- Temp Sensor to Query Manager
Registering a Device
Registering a Device

Diagram:
- Query Manager
- Temp Sensor

Connection:
- Query Manager to Temp Sensor
Configuring an Application
Configuring a Device

Diagram:
- Temp Sensor
- Ambient Light
- Monitor
- Controller
- Heater
- Vent Fan
Configuring a Device

Diagram:
- App
- Query Manager
- Temp Sensor
- Heater
- Ambient Light
- Vent Fan
Configuring a Device
Configuring a Device

Diagram:
- Query Manager
- Temp Sensor
- Heater
- Ambient Light
- App Configure
- Vent Fan

Connections:
- Query Manager to Temp Sensor
- Query Manager to Heater
- Query Manager to Ambient Light
- Query Manager to App Configure
- Query Manager to Vent Fan
- Temp Sensor to Heater
- Temp Sensor to Ambient Light
- Temp Sensor to App Configure
- Temp Sensor to Vent Fan
- Ambient Light to Heater
- Ambient Light to App Configure
- Ambient Light to Vent Fan
- App Configure to Heater
- App Configure to Vent Fan
- Vent Fan to Heater
- Vent Fan to App Configure
Configuring a Device

Diagram showing connections between various components:
- Temp Sensor
- Ambient Light
- Monitor
- Controller
- App Configure
- Query Manager
- Heater
- Vent Fan
Configuring a Device
Existing Models
There is a plethora of literature using traces to develop concurrent semantics. But,

- tailored to a fixed collection of concurrent processes.
- exhaustively overdetermined and processes must be closed over symmetries.
- often assumes a knowledge of states.
- processes often require prefix closures to account for observational states.
- more broadly, observational states are conflated with process states.

And yet, LTL makes this a very supported approach.
Event Systems are worked on by Winskell et al. and provide a more direct, more ontological model for what happens in a process. It is more attractive that the atomic element is an event, but,

- based on partial orders, hence transitive closure.
- compositions are awkward, because of transitive closure.
- relatedly, dependencies are not directly described in an ontological form.
Events are unique instances of something happening in a behavior.

- an operation being performed on a machine.
- a message being sent or received
- a reaction to other events: interrupts, application events, etc...
- a physical quantity being measured as having a certain measurement
- a process being created
Dependencies indicate conditions or information upon which an event depends as a consequence of another event.

- an operation depending on the conclusion of the previous operation in a sequential process
- a message received depending on a message having been sent
- a sensor reaction depending on a physical quantity passing a certain threshold
- a read-blocked operation depending on the reception of a message
- an event-handler firing depending on the appearance of an event
- a read from a message queue depending on the previous read from the same queue
Ontological Event Graphs describe fragments of what happened in a Swarm Process, ontologically, independent of the perspective. They consist of events and dependencies. Dependencies can either be connected to an event or open ended (indicated by the star), suggesting and incoming or outgoing connection to preceding or following events.
OEG Composition

OEGs can be composed in parallel or sequentially by attaching open dependencies. This can be typed, of course.
OEG Prefixes
Perspective
Epistemological Event Graphs
For any two observational states, there are always exist paths to bring them into a common confluent observational state. This is like the Church-Rosser property!
Example: Home Automation
Here, an OEG can be given for a fragment of behavior associated with the actions in the configuration example. Orange arrows are control dependencies, green arrows are communication, and purple arrows are initialization. Red boxes are allocation events.
Conclusions
Progress on this work.

- Currently working on the mathematical details.
- Planning software tools to generate and manipulate OEGs and EEGs
- More examples!?
- Develop languages of assertion and logic formulas.
- Connecting with language design work: ReActors.
Thanksabunch!