Coordination Languages

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2 Linda

3 JavaSpaces

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6 Example Programs

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Background

The term Coordination Language was coined by Gelernter and Carriero in the context of Linda.

Concurrent programming = Computation + Coordination

Since their seminal work, a number of new languages have been proposed and described as coordination languages.

We focus on coordination models based on generative communication via a shared dataspace – theoretically this can be seen as a broadcast mode of communication

Applications: e-commerce, game playing, internet services, workflow management

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Issues

In defining what a coordination language might be there are a number of issues which must be addressed:

1. what are the entities which are being coordinated?
2. what are the media for coordination?
3. what are the protocols and rules used for coordination?

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General Observations

- Coordination languages are not general purpose programming languages, in particular they do not need to be Turing complete; rather, they are usually defined as language extensions or scripting languages.

- Coordination languages are most relevant in the context of open systems, where the coordinated entities are not fixed at the outset.

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Components

- Coordinated entities: There is general agreement that the coordinated entities should be active – agents or processes. Coordination of agents should not require reprogramming; the coordination mechanism is a wrapper around the existing, independent agents.
- Coordination media: Coordination is often accomplished via a shared data space, typically a tuple space, multiset or partitioned (multi-)set. In such models, communication is *generative*.
- Coordination rules In contrast to Linda, many of the recent proposals have been for rule-based languages; one consequence of this shift to a more declarative view of coordination is increased reasoning power.

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Linda

The syntax of $\mathcal{L}(X)$ is formally defined by the following grammar:

$$
\begin{array}{lcl}
P & ::= & \textbf{stop} \mid C.P \mid P \mid P \mid P + P \\
C & ::= & \textbf{ask}(t) \mid \textbf{tell}(t) \mid \textbf{get}(t) \mid \textbf{eval}(P)
\end{array}
$$

t is a generic element called token in a denumerable set $\mathcal{D}$, P is a process and C a communication action (or prefix), the set of all processes is denoted by $\mathcal{P}$.

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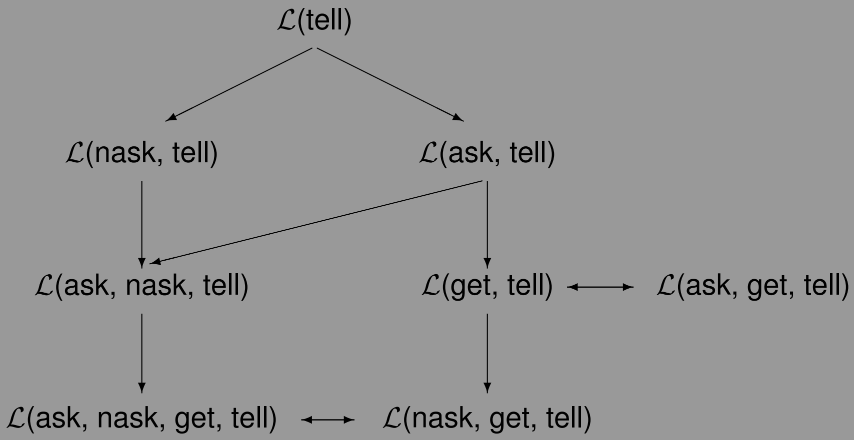
Linda Hierarchy



Dining Philosophers

```
philosopher(int i)
{
  while(TRUE){
   think();
   in(”meal ticket”); in(”fork”,i);
   in(”fork”,(i+1)%5);
   eat()
   out(”fork”,i); out(”fork”,(i+1)%5);
   out(”meal ticket”);
  }
}
```

Dining Philosophers contd.

```
real_main()
{
  int i;
  for (i=0,i<5, i++){
   out(”fork”,i);
   eval(philosopher(i));
   if (i<4) out(”meal ticket”);
  }
}
```

Javaspaces philosophy

- Based on the concept of shared network-based persistent space that is used for both object storage and as an exchange space
- Simple API that is easy to learn but expressive for building sophisticated distributed applications
- Objects are passive.

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JavaSpaces

Four primary operations on a Javaspaces service:

- `write()`: Writes new objects into a space
- `take()`: Retrieves objects from a space
- `read()`: Makes a copy of objects in a space
- `notify`: Notifies a specified object when entries that match the given template are written into a space

KLAIM philosophy

- The KLAIM language (Kernel Language for Agents Interaction and mobility) was introduced by De Nicola et al as a distributed mobile version of Linda
- It extends the Linda interaction model by replacing the single shared tuple space with multiple distributed tuples spaces
- It also allows explicit manipulation of localities and locality names

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KLAIM Syntax

$N \in$ **Net**	N	$::=$	$N_1 \parallel N_2 \mid l :: P \mid l :: \langle \overrightarrow{l} \rangle$
$P \in$ **Proc**	P	$::=$	$P_1 \mid P_2 \mid \sum_i a_i.P_i \mid *P$
$a \in$ **Act**	a	$::=$	$\mathbf{out}(\overrightarrow{\ell})@\ell \mid \mathbf{in}(\overrightarrow{\ell^\lambda})@\ell \mid \mathbf{read}(\overrightarrow{\ell^\lambda})@\ell$
$\ell, \ell^\lambda \in$ **Loc**	ℓ	$::=$	$u \mid l \qquad \ell^\lambda ::= \ell \mid !u$

KLAIM Semantics

- Well-formedness conditions on use of variable names
- Structural Congruence
- Reaction Semantics
- Pattern Matching of Templates against Tuples

KLAIM Example

$$\begin{aligned}\text{User} :: \quad & \mathbf{read}(!\mathit{name}, !\mathit{telno})@\mathrm{YP}. \\ & \mathbf{read}(\mathit{telno}, !\mathit{val}_1, !\mathit{val}_2)@\mathrm{DB}. \\ & \mathbf{out}(\mathit{val}_1)@\mathit{name}\end{aligned}$$

Access Control

- Discretionary Access Control:
  1. Access Control Matrix DAC containing triples (s, o, a)
  2. Whenever User is performing a **read** action on a location l a reference monitor will check whether (User, l, **read**) $\in$ DAC
  3. Similarly for **out** actions
- Mandatory Access Control:
  1. We assign DB the level high and YP the level low
  2. A low user can only perform **read** actions on YP whereas **out** actions can be performed on any location
  3. A high user, on the other hand, will be able to perform **read** actions on both YP and DB. The out action can only be performed on high locations unless a notion of declassification is imposed that will lower the users' security level.

AspectK Syntax

$S \in \textbf{System}$	S	$::=$	$\textbf{let } \overrightarrow{asp} \textbf{ in } N$
$asp \in \textbf{Asp}$	asp	$::=$	$A[cut] \triangleq body$
$body \in \textbf{Advice}$	$body$	$::=$	$\textbf{case}\ (cond)\ sbody\ ;\ body \mid sbody$
	$sbody$	$::=$	$as\ \textbf{break} \mid as\ \textbf{proceed}\ as$
$as \in \textbf{Act}^*$	as	$::=$	$a.as \mid \varepsilon$
$cond \in \textbf{BExp}$	$cond$	$::=$	$\textbf{test}(\overrightarrow{\ell^\lambda})@\ell \mid \ell_1 = \ell_2 \mid cond_1 \wedge cond_2 \mid \neg\ cond$
$cut \in \textbf{Cut}$	cut	$::=$	$\ell :: a$
$\ell^\lambda \in \textbf{Loc}$	ℓ^λ	$::=$	$\ell \mid !u \mid ?u$

AspectK Semantics

$$\frac{N \rightarrow N' \quad \text{(where globally } \Gamma_A = \overrightarrow{asp}\text{)}}{\textbf{let } \overrightarrow{asp} \textbf{ in } N \rightarrow \textbf{let } \overrightarrow{asp} \textbf{ in } N'}$$

$$l_s :: \underline{\textbf{stop}}.P + \cdots \rightarrow l_s :: 0$$

$$l_s :: \underline{\textbf{out}}(\overrightarrow{I})@l_0.P + \cdots \rightarrow l_s :: P \mid\mid l_0 :: \langle \overrightarrow{I} \rangle$$

$$l_s :: \underline{\textbf{in}}(\overrightarrow{\ell^\lambda})@l_0.P + \cdots \mid\mid l_0 :: \langle \overrightarrow{I} \rangle \rightarrow l_s :: P\theta \quad \text{if } match(\overrightarrow{\ell^\lambda}; \overrightarrow{I}) = \theta$$

$$l_s :: \underline{\textbf{read}}(\overrightarrow{\ell^\lambda})@l_0.P + \cdots \mid\mid l_0 :: \langle \overrightarrow{I} \rangle \rightarrow l_s :: P\theta \mid\mid l_0 :: \langle \overrightarrow{I} \rangle \quad \text{if } match(\overrightarrow{\ell^\lambda}; \overrightarrow{I}) = \theta$$

AspectK Semantics contd...

$$\frac{l_s :: \Phi_{\textbf{proceed}}(\Gamma_A; l_s :: \textbf{out}(\overrightarrow{l})@l_0).P \rightarrow N}{l_s :: \textbf{out}(\overrightarrow{l})@l_0.P + \cdots \rightarrow N}$$

$$\frac{l_s :: \Phi_{\textbf{proceed}}(\Gamma_A; l_s :: \textbf{in}(\overrightarrow{\ell^\lambda})@l_0).P \mid\mid N' \rightarrow N}{l_s :: \textbf{in}(\overrightarrow{\ell^\lambda})@l_0.P + \cdots \mid\mid N' \rightarrow N}$$

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The Φ function

- The result of $\Phi_f(\Gamma_A; \ell :: a)$ is a sequence of actions trapping $\ell :: a$; Γ_A is a global environment of aspects. The index f is either **proceed** or **break**
- In the case of **proceed** the action $\underline{a}$ is eventually emitted
- Otherwise the action is dispensed with and replaced by **stop**
- Advice is searched in declaration order and applies in a parenthesis-like fashion.

DAC

Discretionary access control can be imposed by introducing a location DAC containing two kinds of triples

- $\langle \mathit{user}, \mathrm{DB}, \mathbf{read} \rangle$ for selected users, and
- $\langle \mathit{user}, \mathit{name}, \mathbf{out} \rangle$ for the same selected users and all names.

The following aspect declarations will then impose the desired requirements:

$$A^{read}_{\mathrm{DAC}}[u :: \mathbf{read}(?x, ?y, ?z)@\mathrm{DB}] \triangleq \mathbf{case}(\mathbf{test}(u, \mathrm{DB}, \mathbf{read})@\mathrm{DAC})\ \mathbf{proceed};\ \mathbf{break}$$

$$A^{out}_{\mathrm{DAC}}[u :: \mathbf{out}(z)@l] \triangleq \mathbf{case}(\mathbf{test}(u, l, \mathbf{out})@\mathrm{DAC})\ \mathbf{proceed};\ \mathbf{break}$$

DAC contd...

Using aspects it is easy to modify the access control policy so as to allow a user to access his own entries in DB even though he does not have access to the complete database. We simply modify the aspect A^{read}_{DAC} to become

$$A^{read}_{DAC-1}[u :: \textbf{read}(!x, ?y, ?z)@\text{DB}] \triangleq \textbf{break}$$

$$A^{read}_{DAC-2}[u :: \textbf{read}(x, ?y, ?z)@\text{DB}] \triangleq \textbf{case}(\textbf{test}(u, \text{DB}, \textbf{read})@\text{DAC} \vee \textbf{test}(u, x)@\text{YP}) \; \textbf{proceed}; \; \textbf{break}$$

MAC

For the mandatory access control policy we introduce a location MAC with the following pairs:

- $\langle \mathrm{YP}, \mathrm{low} \rangle$ reflecting that the phonebook has low security level,
- $\langle \mathrm{DB}, \mathrm{high} \rangle$ reflecting that the customer database has high security level,
- $\langle s, \mathrm{low} \rangle$ for all users and names s with low security level, and
- $\langle s, \mathrm{high} \rangle$ for all users and names s with high security level.

We now consider the Bell-LaPadula security policy in a setting where both subjects and objects have fixed security levels.

MAC contd ...

The first part of the policy states that a subject is allowed to read or input data from any object provided that the object's security level dominates that of the object; this is captured by the following aspects (which enforce *no read-up*):

$$A^{read_2}_{\mathrm{MAC}}[u :: \mathbf{read}(?x, ?y)@l] \triangleq \mathbf{case}(\neg(\mathbf{test}(u, \mathrm{low})@\mathrm{MAC} \wedge \mathbf{test}(l, \mathrm{high})@\mathrm{MAC})) \quad \mathbf{proceed}; \quad \mathbf{break}$$

$$A^{read_3}_{\mathrm{MAC}}[u :: \mathbf{read}(?x, ?y, ?z)@l] \triangleq \mathbf{case}(\neg(\mathbf{test}(u, \mathrm{low})@\mathrm{MAC} \wedge \mathbf{test}(l, \mathrm{high})@\mathrm{MAC})) \quad \mathbf{proceed}; \quad \mathbf{break}$$

MAC contd ...

The second part of the policy, the star property, allows a subject to write to any object provided that the security level of the object dominates that of the subject. This is captured by the following aspect (enforcing *no write-down*):

$$\begin{aligned} \mathrm{A}^{out}_{\mathrm{MAC}}[u :: \mathbf{out}(z)@l] \quad \triangleq \quad & \mathbf{case}(\neg(\mathbf{test}(u, \mathrm{high})@\mathrm{MAC} \wedge \\ & \mathbf{test}(l, \mathrm{low})@\mathrm{MAC})) \\ & \quad \mathbf{proceed}; \\ & \quad \mathbf{break} \end{aligned}$$

Declassification

In order to allow a high user to write to a low name we may introduce *declassification* of security levels. To keep things simple we may do so by introducing a billing location that does not need to adhere to the security policy and replace the process by:

$$\begin{array}{lll} & \text{User} :: & \mathbf{read}(!name, !key)@\text{YP}. \\ & & \mathbf{read}(key, !val_1, !val_2)@\text{DB}. \\ & & \mathbf{out}(name, val_1, val_2)@\text{Billing} \\ \| & \text{Billing} :: & \mathbf{in}(!n, !v_1, !v_2)@\text{Billing}.\ \mathbf{out}(v_1)@n \end{array}$$

We add the pair $\langle \text{Billing}, \text{high} \rangle$ to the MAC location thereby allowing all high users to output to Billing.

Declassification contd...

We also modify the aspect for **out** actions to ensure that they are always allowed to **proceed** at the Billing location:

$$\mathrm{A}^{out}_{\mathrm{MAC}}[u :: \mathbf{out}(z)@l] \triangleq \mathbf{case}(\neg(\mathbf{test}(u, \mathrm{high})@\mathrm{MAC} \wedge \mathbf{test}(l, \mathrm{low})@\mathrm{MAC}) \vee (u = \mathrm{Billing}))\ \mathbf{proceed};\ \mathbf{break}$$

Logging

As a final example, which illustrates the need for actions both before and after **proceed** we define an aspect which maintains a log of **read** action on DB:

$$A_{\mathrm{LOG}}[u :: \mathbf{read}(?x, ?y, ?z)@\mathrm{DB}] \triangleq \begin{array}{l} \mathbf{in}(sem)@\mathrm{semaphore} \\ \mathbf{proceed} \\ \mathbf{out}(u, x, y, z)@\mathrm{logfile}. \\ \mathbf{out}(sem)@\mathrm{semaphore} \end{array}$$

Conclusions

Features studied:

- Shared space(s) and generative communication
- Located spaces and processes
- Mobility of processes and data
- Aspect-oriented programming
  - Distributed policies
  - Composition of policies
  - Verification

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