Coordination Languages

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Outline

1. Introduction
2. Linda
3. JavaSpaces
4. KLAIM
5. AspectK
6. Example Programs
7. Conclusions
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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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- Coordination languages are most relevant in the context of open systems, where the coordinated entities are not fixed at the outset.
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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The syntax of $\mathcal{L}(X)$ is formally defined by the following grammar:

$$
P : ::= \text{stop} | C.P | P | P | P + P
$$

$$
C : ::= \text{ask}(t) | \text{tell}(t) | \text{get}(t) | \text{eval}(P)
$$

$t$ 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

\[ \mathcal{L}(\text{tell}) \]
\[ \downarrow \]
\[ \mathcal{L}(\text{nask, tell}) \quad \mathcal{L}(\text{ask, tell}) \]
\[ \downarrow \quad \downarrow \]
\[ \mathcal{L}(\text{ask, nask, tell}) \quad \mathcal{L}(\text{get, tell}) \quad \mathcal{L}(\text{ask, get, tell}) \]
\[ \downarrow \quad \downarrow \]
\[ \mathcal{L}(\text{ask, nask, get, tell}) \quad \mathcal{L}(\text{nask, get, tell}) \]
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");
    }
}

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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 Jaavaspaces 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

\[ N \in \text{Net} \quad N ::= N_1 \parallel N_2 \mid I :: P \mid I :: \langle \overrightarrow{I} \rangle \]

\[ P \in \text{Proc} \quad P ::= P_1 \mid P_2 \mid \sum_{i} a_i . P_i \mid *P \]

\[ a \in \text{Act} \quad a ::= \text{out}(\overrightarrow{\ell})@\ell \mid \text{in}(\overrightarrow{\ell^\lambda})@\ell \mid \text{read}(\overrightarrow{\ell^\lambda})@\ell \]

\[ \ell, \ell^\lambda \in \text{Loc} \quad \ell ::= u \mid l \quad \ell^\lambda ::= \ell \mid !u \]
KLAIM Semantics

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

User :: read(name, !telno)@YP.
read(telno, !val_1, !val_2)@DB.
out(val_1)@name
Access Control

- **Discretionary Access Control:**
  1. Access Control Matrix DAC containing triples \((s, o, a)\)
  2. Whenever User is performing a \textbf{read} action on a location \(l\) a reference monitor will check whether \((User, l, \text{read}) \in DAC\)
  3. Similarly for \textbf{out} actions

- **Mandatory Access Control:**
  1. We assign DB the level high and YP the level low
  2. A low user can only perform \textbf{read} actions on YP whereas \textbf{out} actions can be performed on any location
  3. A high user, on the other hand, will be able to perform \textbf{read} actions on both YP and DB. The \textbf{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

\[ S \in \text{System} \quad S ::= \text{let } \overrightarrow{asp} \text{ in } N \]

\[ asp \in \text{Asp} \quad asp ::= A[cut] \triangleq body \]

\[ body \in \text{Advice} \quad body ::= \text{case} (\text{cond}) \text{sbody ; body} \mid \text{sbody} \]

\[ sbody ::= \text{as} \break \mid \text{as} \proceed \text{ as} \]

\[ as \in \text{Act}^* \quad as ::= a.as \mid \varepsilon \]

\[ cond \in \text{BExp} \quad cond ::= \text{test}(\overrightarrow{\lambda})@l \mid l_1 = l_2 \mid \]

\[ cond_1 \land cond_2 \mid \neg cond \]

\[ cut \in \text{Cut} \quad cut ::= l :: a \]

\[ \ell^\lambda \in \text{Loc} \quad \ell^\lambda ::= l \mid !u \mid ?u \]
AspectK Semantics

\[ N \rightarrow N' \text{ (where globally } \Gamma_A = \overrightarrow{asp}) \]

\[ \text{let } \overrightarrow{asp} \text{ in } N \rightarrow \text{let } \overrightarrow{asp} \text{ in } N' \]

\[ l_s :: \text{stop}.P + \cdots \rightarrow l_s :: 0 \]

\[ l_s :: \text{out}(\overrightarrow{l})@l_0.P + \cdots \rightarrow l_s :: P \parallel l_0 :: \langle \overrightarrow{l} \rangle \]

\[ l_s :: \text{in}(\overrightarrow{l^\lambda}@l_0.P + \cdots \parallel l_0 :: \langle \overrightarrow{l} \rangle \rightarrow l_s :: P\theta \]

\[ \text{if } \text{match}(\overrightarrow{l^\lambda}; \overrightarrow{l}) = \theta \]

\[ l_s :: \text{read}(\overrightarrow{l^\lambda}@l_0.P + \cdots \parallel l_0 :: \langle \overrightarrow{l} \rangle \rightarrow l_s :: P\theta \parallel l_0 :: \langle \overrightarrow{l} \rangle \]

\[ \text{if } \text{match}(\overrightarrow{l^\lambda}; \overrightarrow{l}) = \theta \]
AspectK Semantics contd...

\[
\begin{align*}
I_S &:: \Phi_{\text{proceed}}(\Gamma_A; I_S :: \text{out}(\overrightarrow{I})@l_0).P \rightarrow N \\
I_S &:: \text{out}(\overrightarrow{I})@l_0.P + \cdots \rightarrow N \\
I_S &:: \Phi_{\text{proceed}}(\Gamma_A; I_S :: \text{in}(\overrightarrow{\ell\lambda})@l_0).P || N' \rightarrow N \\
I_S &:: \text{in}(\overrightarrow{\ell\lambda})@l_0.P + \cdots || N' \rightarrow N \\
I_S &:: \Phi_{\text{proceed}}(\Gamma_A; I_S :: \text{read}(\overrightarrow{\ell\lambda})@l_0).P || N' \rightarrow N \\
I_S &:: \text{read}(\overrightarrow{\ell\lambda})@l_0.P + \cdots || N' \rightarrow N
\end{align*}
\]
The $\Phi$ function

- The result of $\Phi_f(\Gamma_A; \ell :: a)$ is a sequence of actions trapping $\ell :: a$; $\Gamma_A$ is a global environment of aspects. The index $f$ is either **proceed** or **break**.

- In the case of **proceed** the action $a$ 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.
Discretionary access control can be imposed by introducing a location DAC containing two kinds of triples

- \( \langle user, DB, read \rangle \) for selected users, and
- \( \langle user, name, out \rangle \) for the same selected users and all names.

The following aspect declarations will then impose the desired requirements:

\[
A_{DAC}^{\text{read}}[u :: \text{read}(?x, ?y, ?z)@DB] \triangleq \text{case}(\text{test}(u, DB, read)@DAC)\;\text{proceed};\;\text{break}
\]

\[
A_{DAC}^{\text{out}}[u :: \text{out}(z)@l] \triangleq \text{case}(\text{test}(u, l, out)@DAC)\;\text{proceed};\;\text{break}
\]
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 $A_{DAC}^{read}$ to become

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

\[ A_{DAC}^{read-2}[u :: \text{read}(x, ?y, ?z)@DB] \triangleq \text{case(test}(u, DB, \text{read})@DAC \lor \text{test}(u, x)@YP) \]

\[ \text{proceed;} \]

\[ \text{break} \]
MAC

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

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

\[ A_{\text{MAC}}^{\text{read}_2}[u :: \text{read}(?x, ?y)@l] \triangleq \text{case}(\neg(\text{test}(u, \text{low})@\text{MAC} \land \\
\text{test}(l, \text{high})@\text{MAC})) \]

\[ \text{proceed}; \]

\[ \text{break} \]

\[ A_{\text{MAC}}^{\text{read}_3}[u :: \text{read}(?x, ?y, ?z)@l] \triangleq \text{case}(\neg(\text{test}(u, \text{low})@\text{MAC} \land \\
\text{test}(l, \text{high})@\text{MAC})) \]

\[ \text{proceed}; \]

\[ \text{break} \]
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 \textit{no write-down}):

\[
A^{out}_{MAC}[u :: \texttt{out}(z)@l] \triangleq \text{case}(\neg (\texttt{test}(u, \text{high})@MAC \land \\
\texttt{test}(l, \text{low})@MAC)) \\
\text{proceed;} \\
\text{break}
\]
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:

```
User :: read(!name, !key)@YP.
      read(key, !val₁, !val₂)@DB.
      out(name, val₁, val₂)@Billing
|| Billing :: in(!n, !v₁, !v₂)@Billing. out(v₁)@n
```

We add the pair ⟨Billing, high⟩ to the MAC location thereby allowing all high users to output to Billing.
Declassification contd...

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

\[
A_{MAC}^{out}[u :: \textbf{out}(z)@l] \triangleq \text{case}\left(\neg (\text{test}(u, \text{high})@MAC \land \text{test}(l, \text{low})@MAC) \lor (u = \text{Billing})\right) \begin{cases} \text{proceed;} \\ \text{break} \end{cases}
\]
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:

\[
A_{\log}[u :: read(?x, ?y, ?z)_{DB}] \triangleq in(sem)@semaphore
proceed
out(u, x, y, z)@logfile.
out(sem)@semaphore
\]
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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End Notes

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