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Privacy Enforcement and Analysis for Functional Active Objects

Florian Kammüller

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Data Privacy Management

Athens, 23. September 2010

Motivation and goals

- Language analysis with interactive theorem provers (HOL)
“Killer-Application” (Java, C)
- We develop new language ASP_{fun} in Isabelle/HOL:
calculus of functional, active objects, distributed, plus
typing
- ⇒ Explore language based security for distributed active
objects;
- ⇒ Enforce and analyse privacy by flexible parameterization
(currying)
- ⇒ Long-term goal: Language based assembly kit for
distributed security (LB-MAKS)

Overview

- 1 ASP_{fun}
- 2 Example for ASP_{fun} : Service Triangle
- 3 Privacy Enforcement and Analysis

ASP_{fun} – Asynchronous Sequential Processes – functional

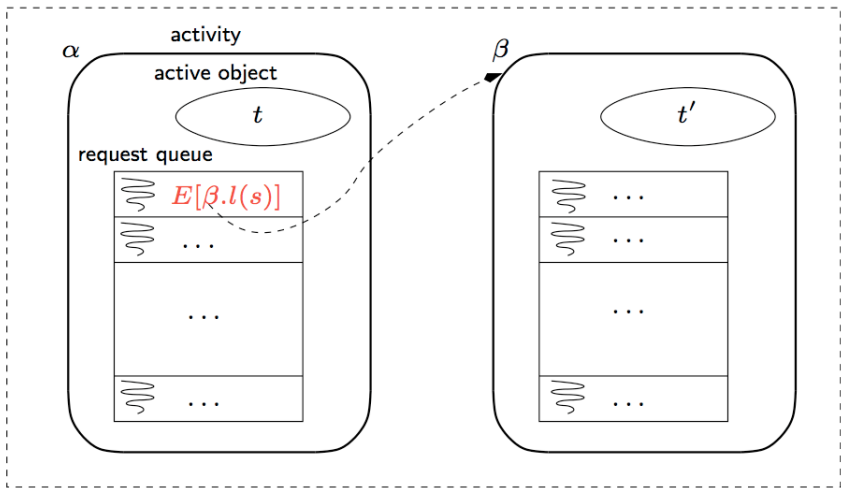
- ProActive (Inria/ActiveEON): Java API for active objects



- New calculus ASP_{fun} for ProActive
 - Asynchronous communication with *Futures*
 - Futures are *promises* to results of method calls
 - Futures enable asynchronous communication
- ⇒ ASP_{fun} avoids deadlocks when accessing futures

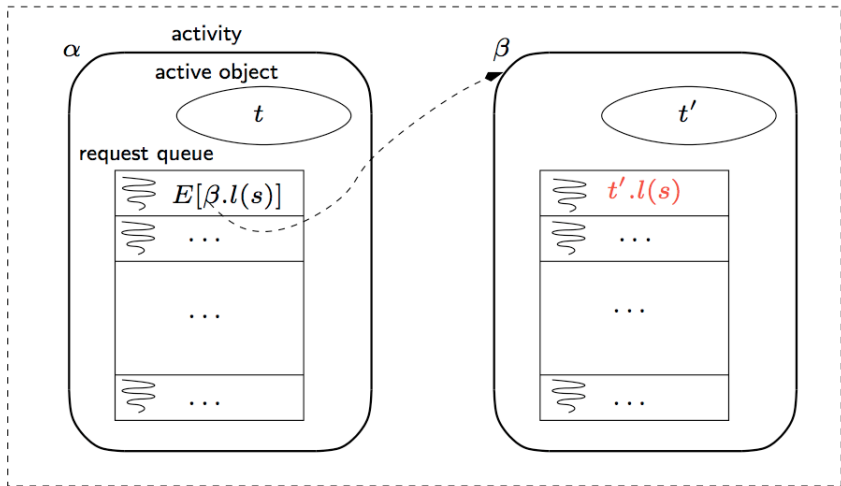
ASP_{fun}: at a glance

configuration



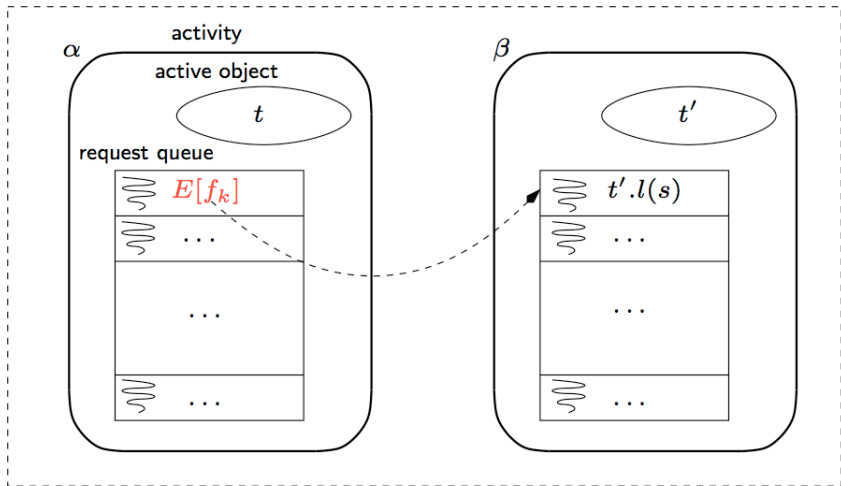
ASP_{fun}: at a glance

configuration



ASP_{fun}: at a glance

configuration



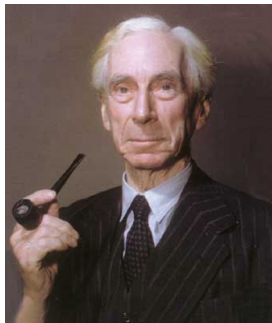
Informal semantics of ASP_{fun}

Local (ζ -calculus) and *parallel* (configuration) semantics

- **LOCAL**: reduction \rightarrow_{ζ} of ζ -calculus.
- **ACTIVE**: *Active*(t) creates a new activity $\alpha[\emptyset, t]$ for new name α , empty request queue, and with t as active object.
- **REQUEST**: *method call* $\beta.l$ creates new future f_k in future-list of activity β .
- **REPLY**: *returns result*, i.e. replaces future f_k by referenced result term s (possibly not fully evaluated).
- **UPDATE-AO**: *activity update* creates a copy of activity and updates active object of copy – original remains the same (*immutable*).

Language development in Isabelle/HOL

- Isabelle/HOL: interactive theorem prover for HOL
- Generic theorem prover
- Formalization of arbitrary object logics
- Interactive proof, tactic support
- Notation close to paper style
- We completely formalized syntax, semantics, and type system of ASP_{fun} , and proved language properties.
- Proof of type safety for ASP_{fun} : preservation and progress (deadlock freedom)



Example: service broker

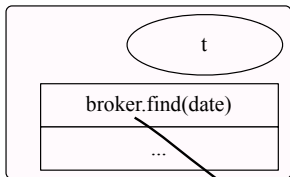
Customer reserves a hotel using a *broker*

```
customer[ $f_0 \mapsto$  broker.find(date),  $t$ ]  
|| broker[ $\emptyset$ , [find =  $\varsigma(x, date)$ hotel.room(date), ...]]  
|| hotel[ $\emptyset$ , [room =  $\varsigma(x, date)$ bookingref, ...]]
```

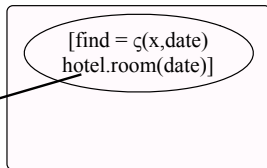
Example: service broker

Customer reserves a hotel using a *broker*

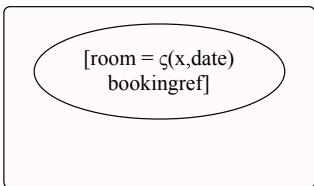
customer



broker



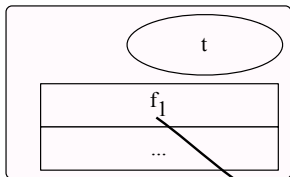
hotel



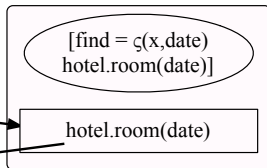
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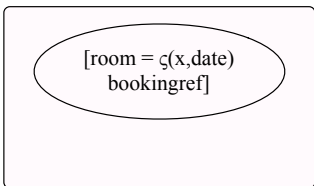
customer



broker



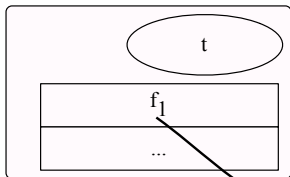
hotel



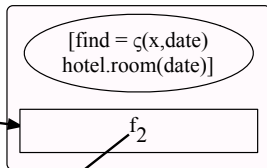
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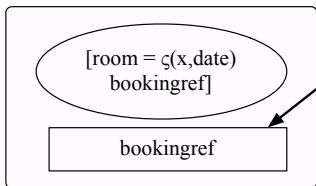
customer



broker



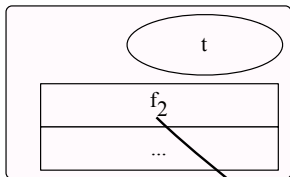
hotel



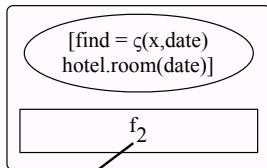
Example: service broker

Customer reserves a hotel using a *broker*

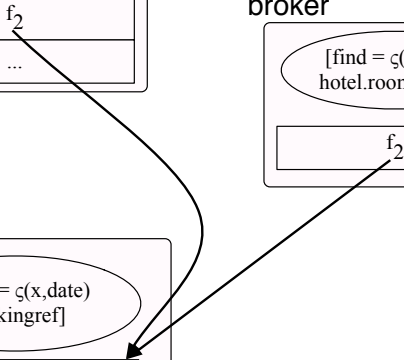
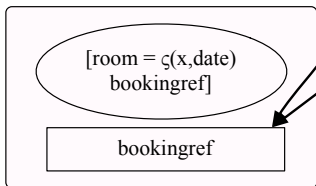
customer



broker



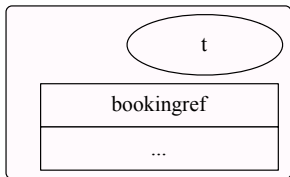
hotel



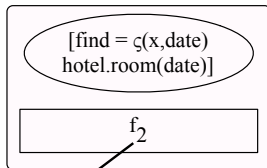
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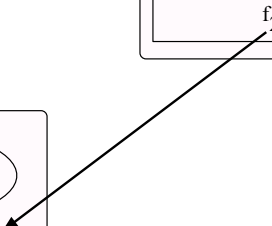
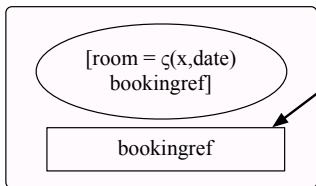
customer



broker



hotel



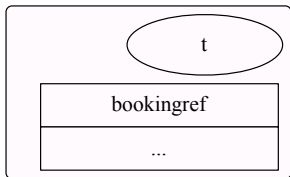
Observations

- Service broker has a private domain of hotel addresses, negotiates and only replies selected hotel or bookingref to customer.
- Client receives `bookingref` using f_2 without viewing details of the hotel nor others from broker's domain.
- It would be nice if the reply `bookingref` would also be private to customer, but . . .

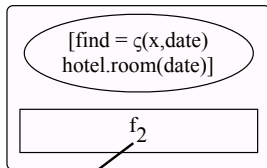
Example: service broker

... broker has also f_2 and can thus get customer's bookingref.

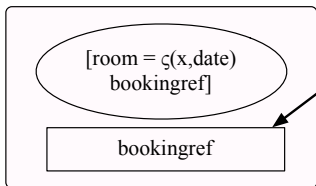
customer



broker



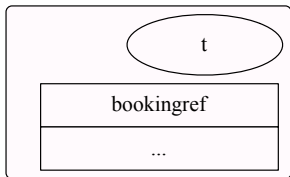
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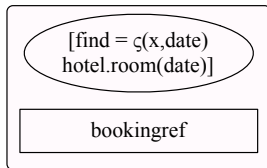
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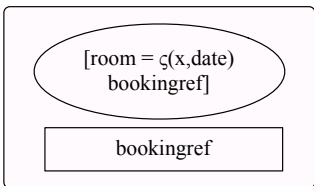
customer



broker



hotel

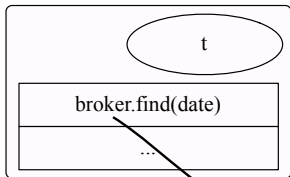


Function Replies for Privacy

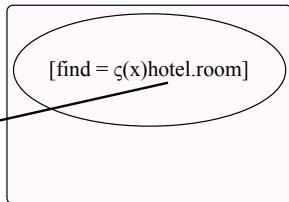
- Idea: avoid communication of private data
- ⇒ Use the **reply of functions** in ASP_{fun}
- Example broker with **private** parameter *date*
 - Client requests booking *without disclosing parameter date*
 - Hotel returns function $y \rightarrow \text{bookingref}$ to client
 - Client calculates his individual **bookingref** by supplying parameter *date* afterwards

Private Hotel Reservation

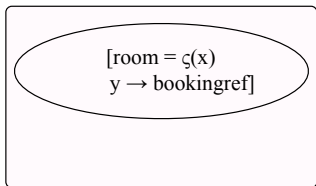
customer



broker

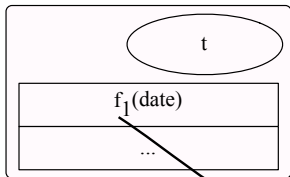


hotel

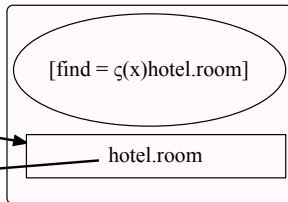


Private Hotel Reservation

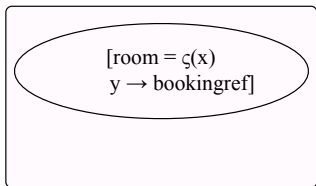
customer



broker



hotel



$f_1(\text{date})$

t

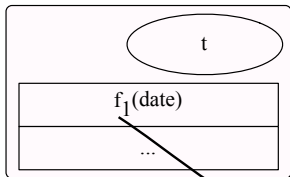
$[\text{find} = \zeta(x)\text{hotel.room}]$

hotel.room

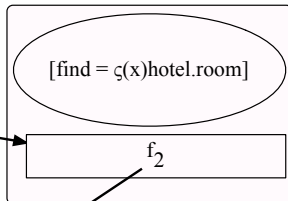
$[\text{room} = \zeta(x)$
 $y \rightarrow \text{bookingref}]$

Private Hotel Reservation

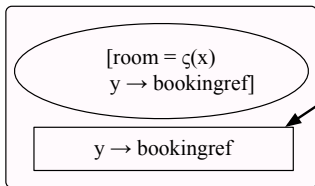
customer



broker

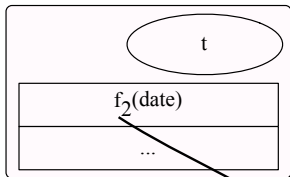


hotel

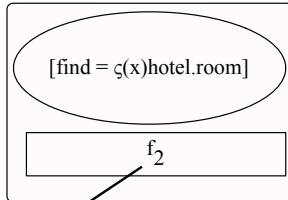


Private Hotel Reservation

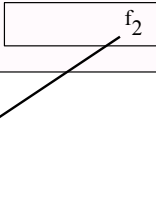
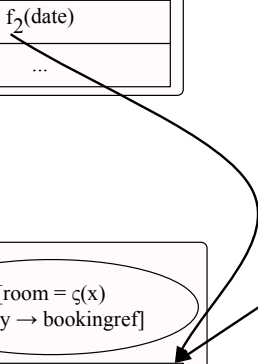
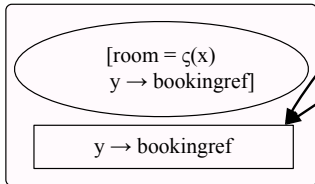
customer



broker



hotel



Stock Taking

- Two versions of broker example:
 1. broker preserves his privacy (futures)
 2. customer can keep his data private as well (currying)
- Private booking 2. uses currying, so is data secure?
- ⇒ Implementation of ASP_{fun} in Erlang supports currying
- Can we provide analysis support for privacy?
- ⇒ (Language Based) Information Flow Control for ASP_{fun}

Contribution

- Formal definitions for ASP_{fun} of:
 - *Hiding* of object labels Δ in object o : $o \setminus \Delta$
 - *Noninterference* (formal definition of information flow security) based on hiding

⇒ Currying is a means for privacy enforcement

⇒ Prove formally “No information flow to public” in curried broker example using formal definitions

but Tedious analysis of all possible program evaluations

⇒ Define type systems for efficient security verification

Conclusions

- ASPEN_{DFG}: Security analysis of distributed active objects
 - Co-development of a new language ASP_{fun} in Isabelle/HOL
 - Isabelle/HOL: type safe and deadlock free
 - Erlang interpreter prototype of ASP_{fun}
- Broker example illustrates privacy enforcement
- Information flow control to analyse security: expensive analysis (type systems)
- Outlook: LB-MAKS for ASP_{fun}: compositionality of security properties

Current papers

- [1] L. Henrio, F. Kammüller. A Mechanized Model of the Theory of Objects. *Formal Methods for Open Object-Based Distributed Systems, FMOODS'07*. LNCS **4468**, 2007.
- [2] F. Kammüller. Formalizing Noninterference for Bytecode in Coq. *Formal Aspects of Computing*: **20**(3):259–275. Springer, 2008.
- [3] L. Henrio and F. Kammüller. Functional Active Objects: Typing and Formalisation. *Foundations of Coordination Languages and System Architectures, FOCLASA'09*. Satellite to ICALP'09. ENTCS, 2009. Also invited to *Science of Computer Programming*.
- [4] F. Kammüller and R. Kammüller. Enhancing Privacy Implementations of Database Enquiries. *The Fourth International Conference on Internet Monitoring and Protection*. IEEE, 2009. Also *Int. Journal on Advances in Security* **2**(2 + 3), 2009.
- [5] F. Kammüller. Using Functional Active Objects to Enforce Privacy. *5th Conf. on Network Architectures and Information Systems Security*. Menton, 2010.
- [6] A. Fleck and F. Kammüller. Implementing Privacy with Erlang Active Objects *Int. Conference on Internet Monitoring and Protection*. 2010.
- [7] F. Kammüller. Privacy Enforcement and Analysis for Functional Active Objects. *5th International Workshop on Data Privacy Management, DPM2010*, co-located with ESORICS 2010.