Communicatin Centered Programming for Embedded Systems

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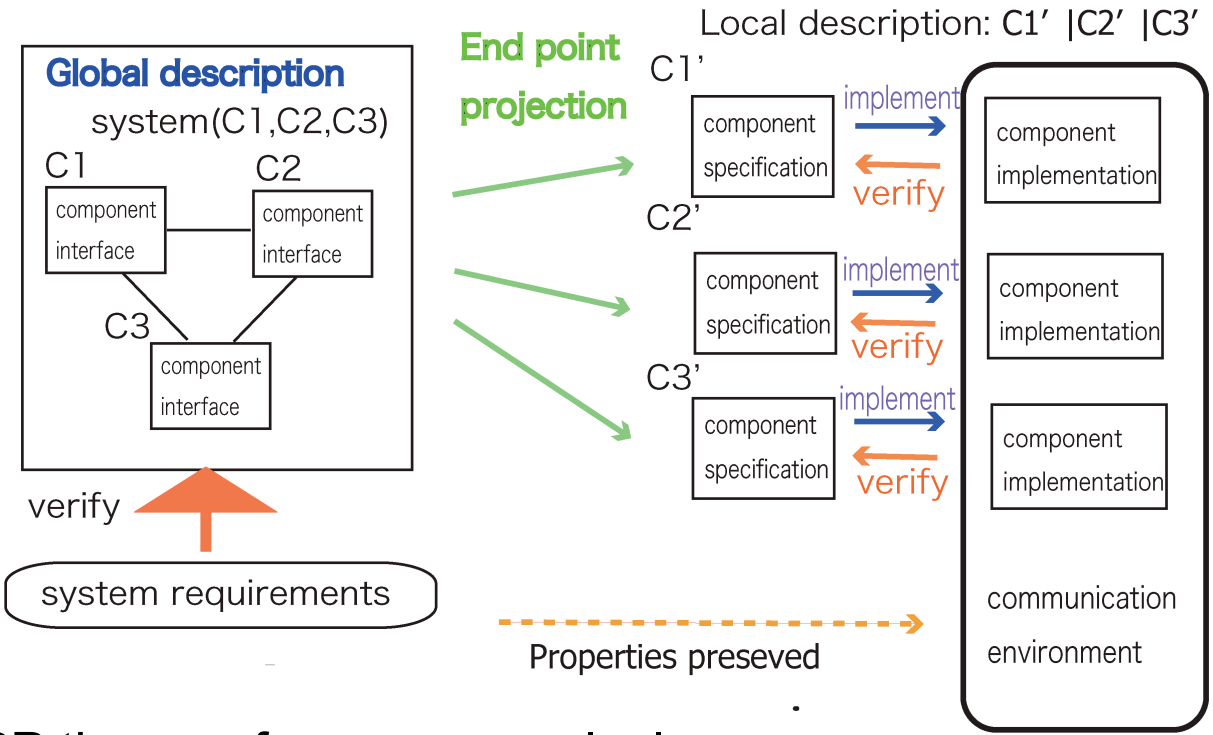
Motivation: Behavior descriptions for embedded system software

- Embedded systems in multi/many cores
  Many cores are cheaper
- Control over critical components
  Verification/Certification
- Low-level coding
  Direct real-time device control (by interrupt)
- Time-aware behavior
  Real-time constraints

Target Overview



EPP theory of a process calculus:

System(C1,C2,C3) ∽ C1'|C2'|C3"

Does this work for embedded system software?

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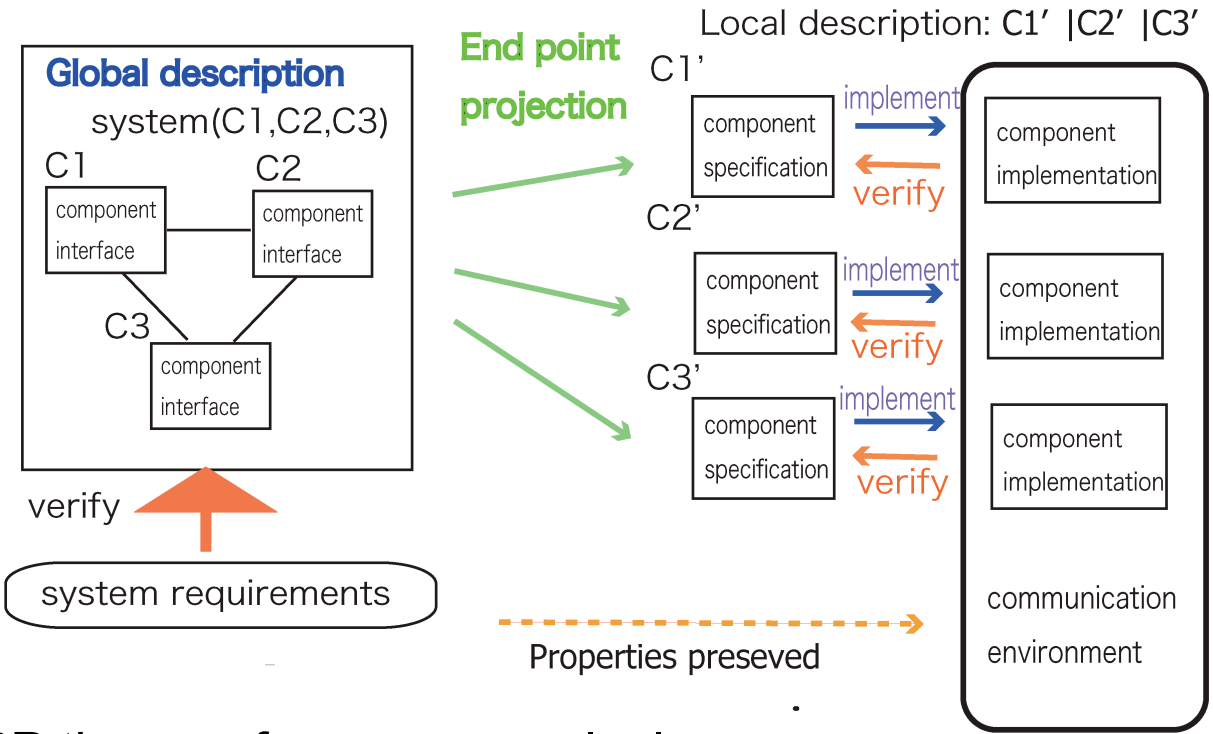

EPP theory of a process calculus:

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Does this work for embedded system software?

extension is necessary

Contents

- Overview of Communication Centered Programming
- Extension with Priority (in Home Appliance Network)
- Concluding Remarks and Future Directions

Communication Centered Programming [Carbone,Honda,Yoshida06]

Global Description：Communication between agents

$$A \to B : s\langle \mathsf{op}, v, x \rangle.I$$

Send message (op,v) in session s and v is stored in x at B

Local Description: Behavior at each agent

$$A[\overline{s}\langle \mathsf{op}, v \rangle.P_A] \mid B[s(\mathsf{op}, x).P_B]$$

Endpoint Calculus : (A version of) typed π calculus

Transformation from GD to LD: End-point Projection

Behavioral correctness: bisimularity

Communication correctness: session type

To Ensures EPP for GD=3 type principles

Communication Centered Programming for WS

CCP is successfully applied for Web Services

CCP implements 'Choreograpy' in Web Services

Business Protocol/SOA for enterprise systems

$$
\begin{aligned}
&Buyer \to Seller : ch_{B2S}(\nu s).Seller \to Buyer : s\langle \mathsf{ack} \rangle.\\
&Buyer \to Seller : s\langle \mathsf{reqQuote} \rangle.\\
&Seller \to Buyer : s\langle \mathsf{QuoteRes}, v_{quote}, x_{quote} \rangle.\\
&(Buyer \to Seller : s\langle QuoteRej \rangle.0\\
&+Buyer \to Seller : s\langle QuoteAcc \rangle.\\
&\quad Seller \to Shipper : ch_{S2Sh}(\nu s').\\
&\quad Shipper \to Seller : s\langle \mathsf{ack} \rangle.\\
&\quad Seller \to Shipper : s'\langle \mathsf{ReqDelDet}, id_{buyer}, x_{client} \rangle.\\
&\quad Shipper \to Seller : s'\langle \mathsf{DelDet}, \mathsf{DD}, x_{DD} \rangle.\\
&\quad Seller \to Buyer : s\langle \mathsf{DelDet}, x_{DD}, y_{DD} \rangle.0)
\end{aligned}
$$

Global Description

Syntax of **Interaction** I:

$$
\begin{array}{rcll}
I & ::= & A \to B : ch(\nu \tilde{s}).I & \text{(init)} \\
& | & A \to B : s\langle \mathsf{op}, e, y \rangle.I & \text{(com)} \\
& | & x@A := e.I & \text{(assign)} \\
& | & \text{if } e@A \text{ then } I_1 \text{ else } I_2 & \text{(conditional)} \\
& | & I_1 + I_2 & \text{(sum)} \\
& | & I_1 | I_2 & \text{(par)} \\
& | & (\nu s)I & \text{(new)} \\
& | & X^A & \text{(recVar)} \\
& | & \mathsf{rec} X^A.I & \text{(rec)} \\
& | & 0 &
\end{array}
$$

Operational Semantics $(I, \sigma) \to (I', \sigma')$

Interaction I with assingment σ becomes I' with σ' after one communication

Local Description

$$
\begin{array}{rcll}
P & ::= & !ch(\tilde{s}).P & \text{(init-in)} \\
 & | & \overline{ch}(\nu\tilde{s}).P & \text{(init-out)} \\
 & | & s \rhd \Sigma_i \mathsf{op}_i(x_i).P_i & \text{(input)} \\
 & | & \overline{s} \lhd \mathsf{op}\langle e\rangle.P & \text{(output)} \\
 & | & x := e.P & \text{(assignment)} \\
 & | & \text{if } e \text{ then } P_1 \text{ else } P_2 & \text{(conditional)} \\
 & | & P_1 \oplus P_2 & \text{(internal sum)} \\
 & | & P_1 | P_2 & \text{(parallel)} \\
 & | & (\nu s)P & \text{(res)} \\
 & | & X & \text{(variable)} \\
 & | & \mathsf{rec}X.P & \text{(recursion)} \\
 & | & 0 & \text{(inaction)}
\end{array}
$$

$$
\begin{array}{rcll}
N & ::= & A[P]_\sigma & \text{(participant)} \\
 & | & N_1 | N_2 & \text{(parallel-nw)} \\
 & | & (\nu s)N & \text{(res-nw)} \\
 & | & \varepsilon &
\end{array}
$$

Behavioral semantics : $N \rightarrow N'$

Defined by π-like SOS rules

Well-structuredness in Global descriptions

- Three principles for global descriptions
  - Connectedness
  - Well-threadedness
  - Coherence

Well-typed in session types $\Gamma \vdash I \triangleright \Delta$

(Example) $\Gamma = \emptyset$ I : interaction among Buyer,Seller,Shipper

$$\Delta = ch_{B2S}@Seller(s)[Buyer, Seller] : \alpha \cdot$$
$$ch_{S2Sh}@Shipper(s')[Seller, Shipper] : \alpha'$$
$$\alpha = s \uparrow \mathsf{ReqQuote}() \cdot s \downarrow \mathsf{QuoteRes}(\mathsf{QuoteType}).(s \uparrow \mathsf{QuoteRej}() +$$
$$s \uparrow \mathsf{QuoteAcc}().s \downarrow \mathsf{DelDet}(\mathsf{DDType}))$$

EPP (End Point Projection)

Let $\mathcal{A}$ be a consistent thread annotation of I.
The end-point projection of $\mathcal{A}$ under σ:

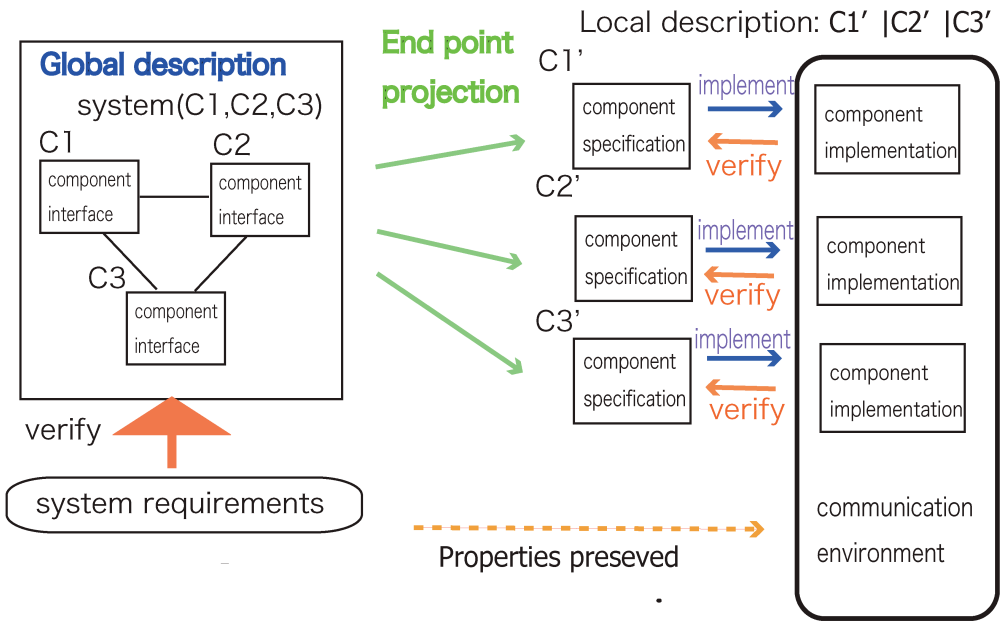
$$EPP((\nu\tilde{s})\mathcal{A},\sigma) = (\nu\tilde{s})\Pi_{A\in Part(I)}A[\Pi_{[\tau]}\sqcup_{\tau'\in[\tau]}TP(\mathcal{A},\tau')]_{\sigma@A}$$

Theorem

1. EPP preserves the session type
2. EPP generates sound and complete local descriptions. (Up to structural congruence and pruning)

Application to Embedded systems

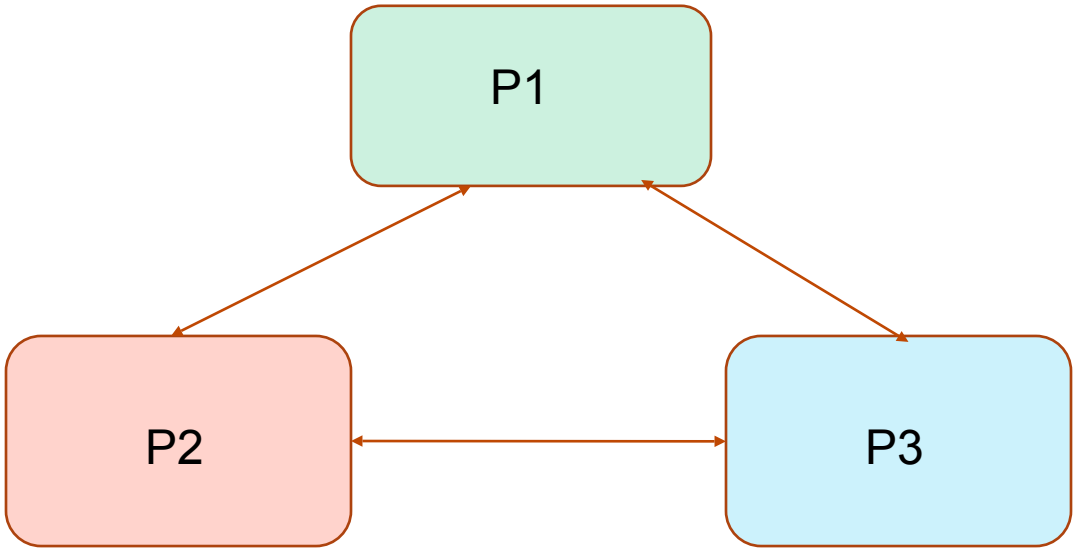
Framwork for system development (not limited to embedded systems)



- Embedded Systems requires more properties real-time, Priority, (and probability)

  Extension in syntax/semantics

Priority in choreography



P1 communicates with P3 unless P2 wishes to communicate
P2 communicates with P3 unless P1 wishes to communicate
P3 communicates with P2 unless P1 wishes to communicate

Globally: P1>P2>P3

Can the global priority be extended in local priority?

on the limited form of Global Descriptions (Guarded/Regular)

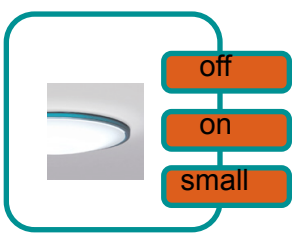
Services in Home Network System

- SOA Based Home Network System
  - ☑ Due to the dynamic nature of home appliance network
  - ☑ No centralized server exists
  - ☑ Appliances can be dynamically added and modified

Appliances export their own features to the network

DVD Player

TV



Light

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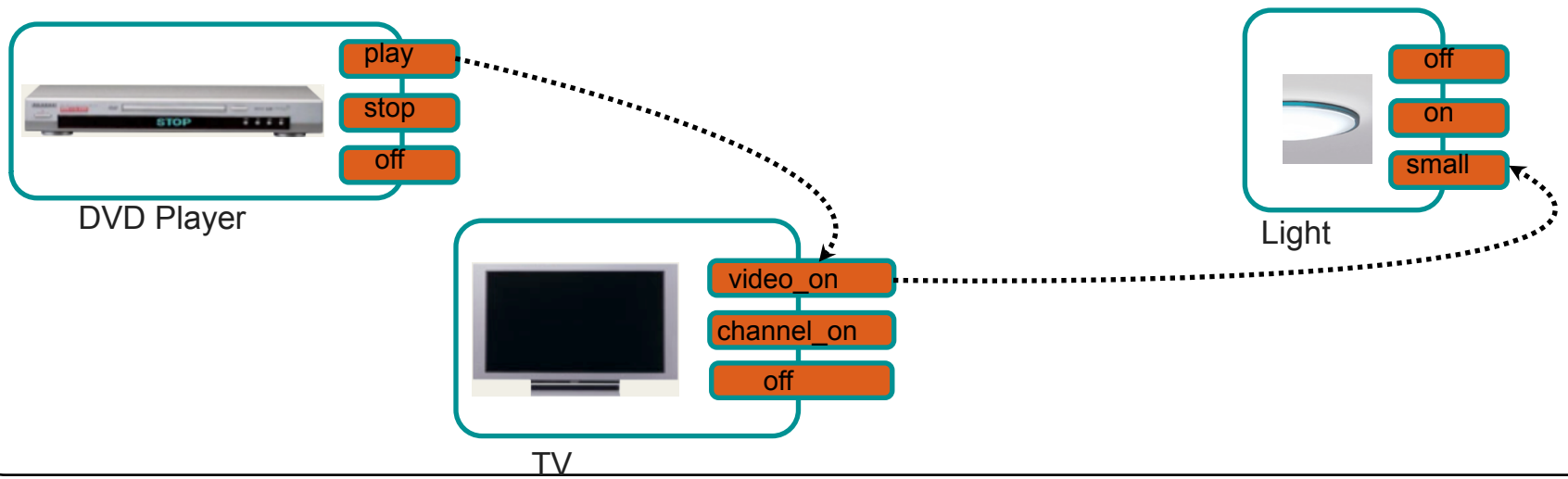

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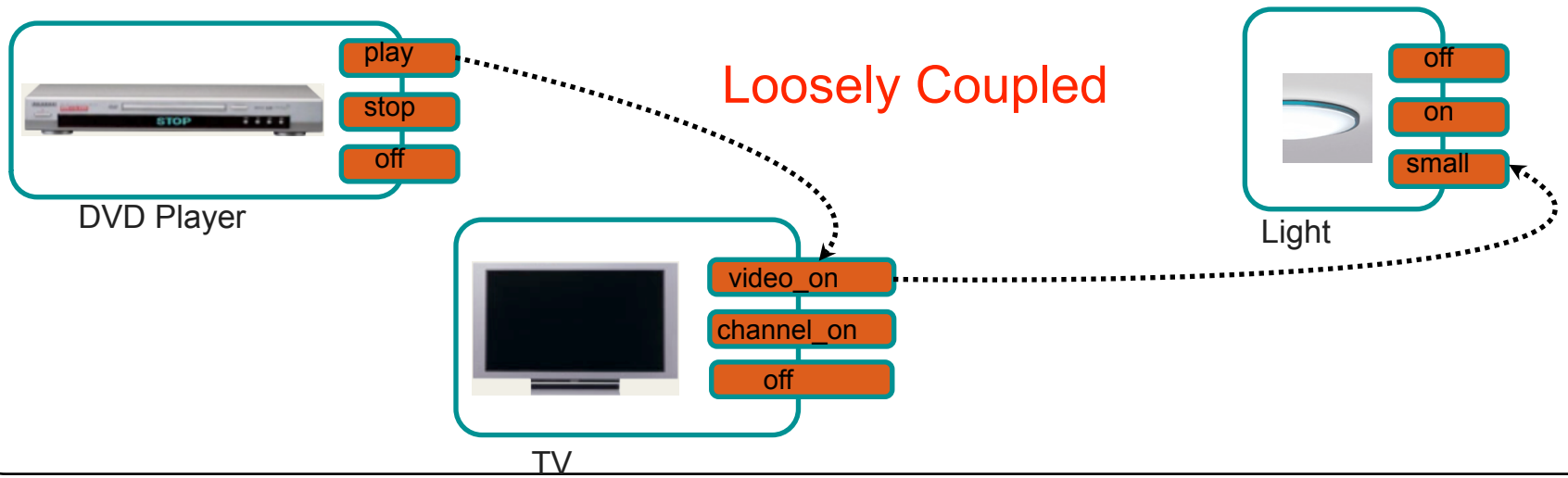
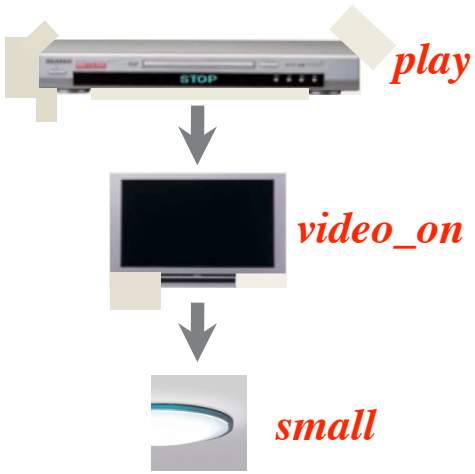


CCP for home appliances

- Example of DVD play interaction



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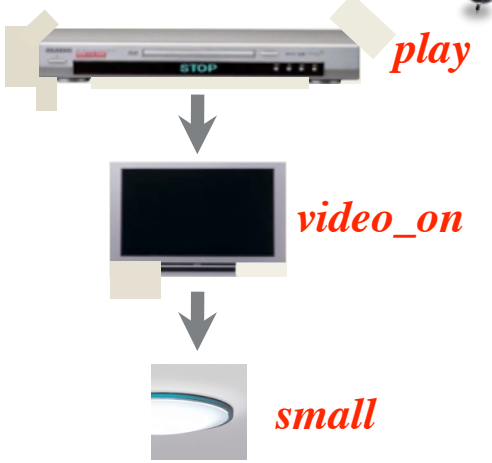

Global Description

USER → DVD : ch_{DVD} (νsDVD).
DVD → TV : ch_{TV} : (νtDVD).
TV → LIGHT1 : ch_{LIGHT1} (νuDVD).
USER → DVD : s_{DVD}<*play*>.
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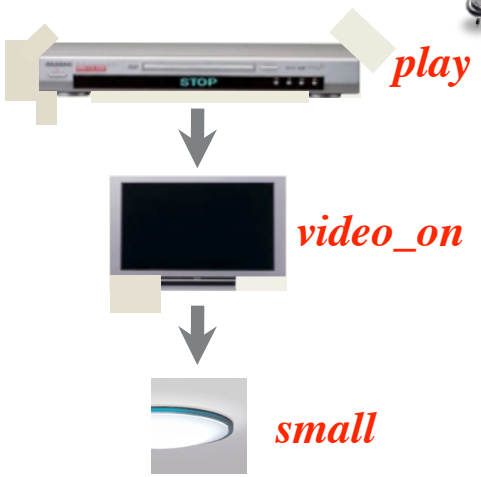

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EPP

Local Descriptions

DVD [ch_{DVD}(νs). ch_{TV}(νs).
s ▷ *play*. s ◁ *video_on*.]

TV [!ch_{TV}(νt). ch_{LIGHT1}(νu).
t ▷ *video_on*. u ◁ *small*]

LIGHT1 [!ch_{LIGHT1}(νu).
u ▷ *small*]



Behavioral interference

An interference example between the DVD Play Interaction and the Coming Home Interaction

User plays the DVD

User opens the Door

The TV is set to the video mode

The air conditioner switches on

The light turns off

The light turns on

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Interference... a phenomenon where two interactions include two different functions of a common appliance

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Interference occurs

Interference... a phenomenon where two interactions include two different functions of a common appliance

We assign priority to each interaction which can conflict with others

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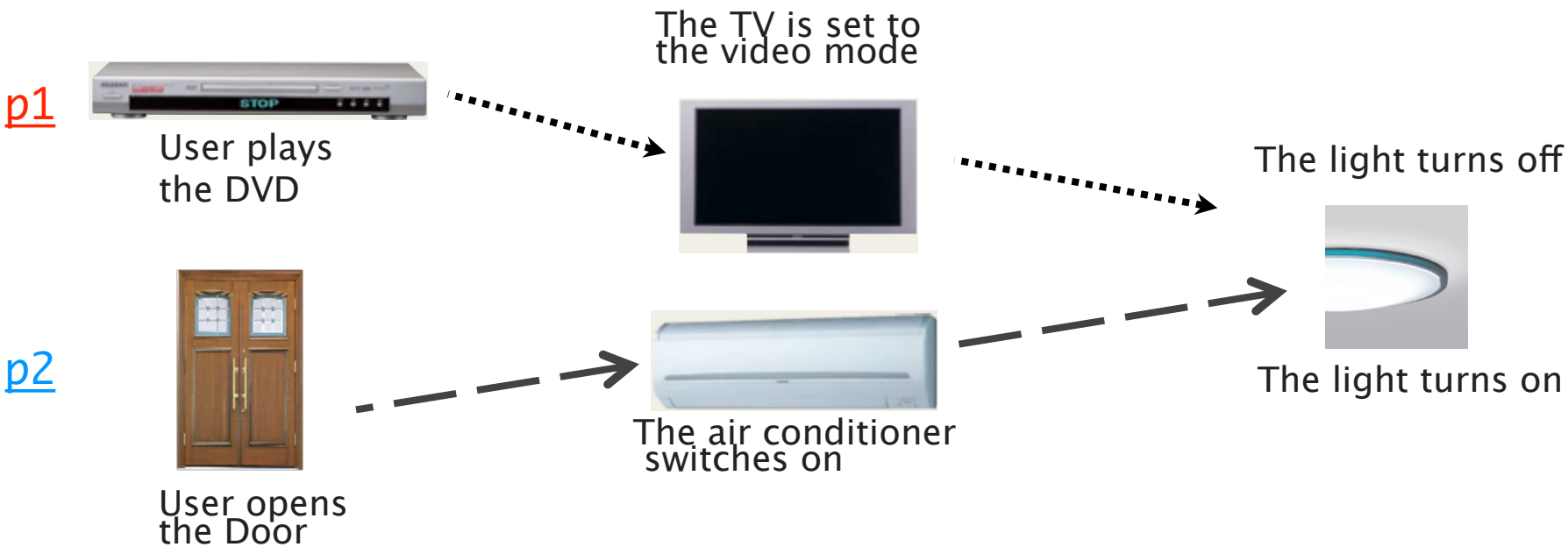

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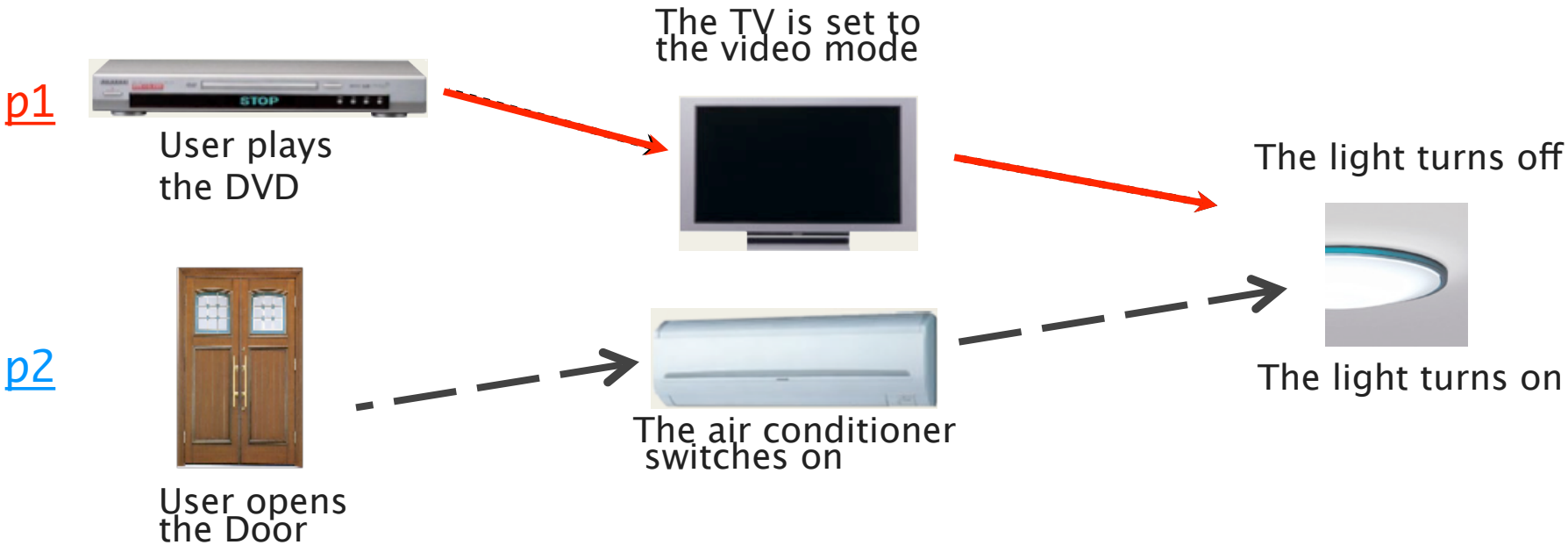

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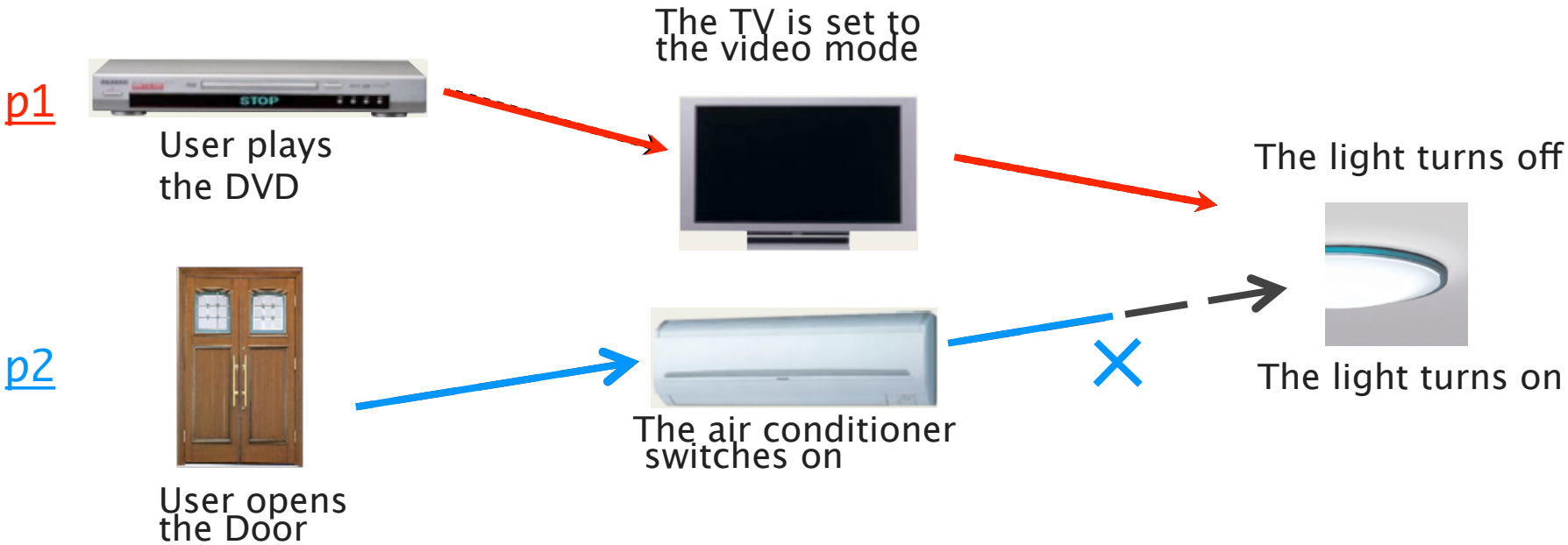


Behavioral interference

An interference example between the DVD Play Interaction and the Coming Home Interaction

p1

User plays the DVD

The TV is set to the video mode

The light turns off

p2

User opens the Door

The air conditioner switches on

The light turns on

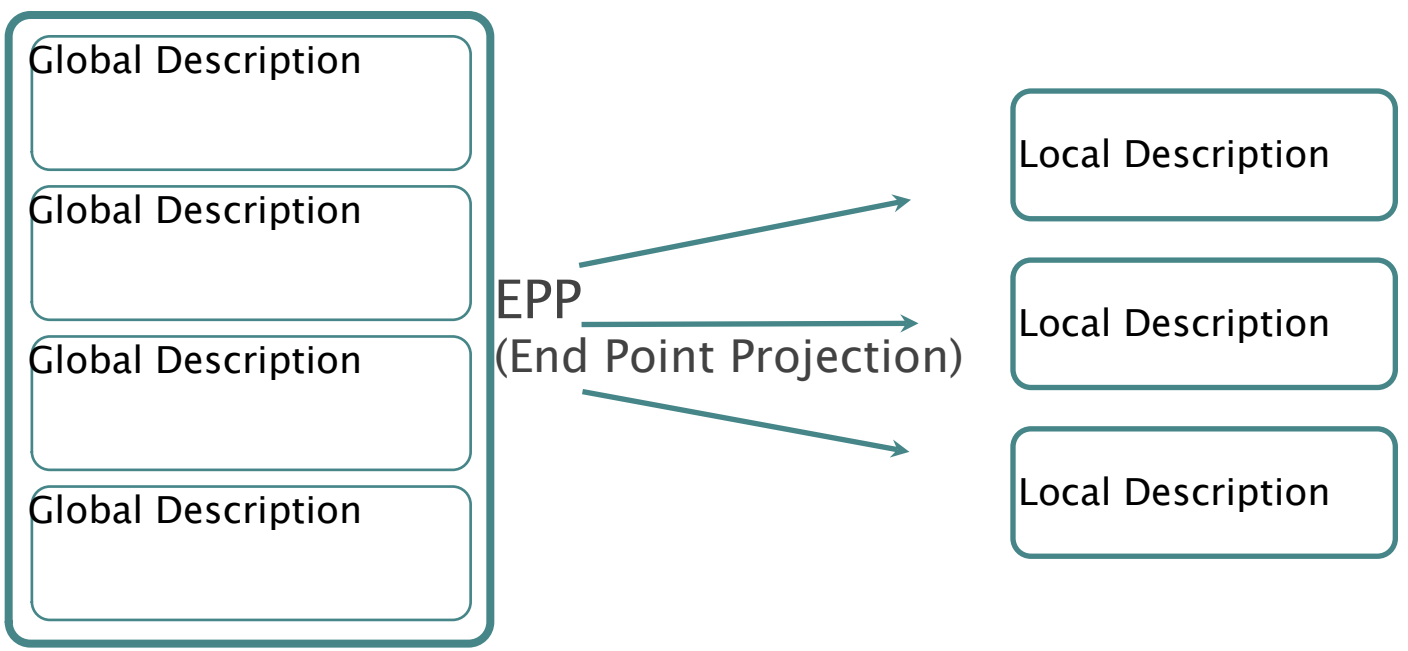
interference will not occur !!

Priority wrt CCP

- To resolve interference within the Communication Centered Programming...

Integrated Services

Appliance Behavior



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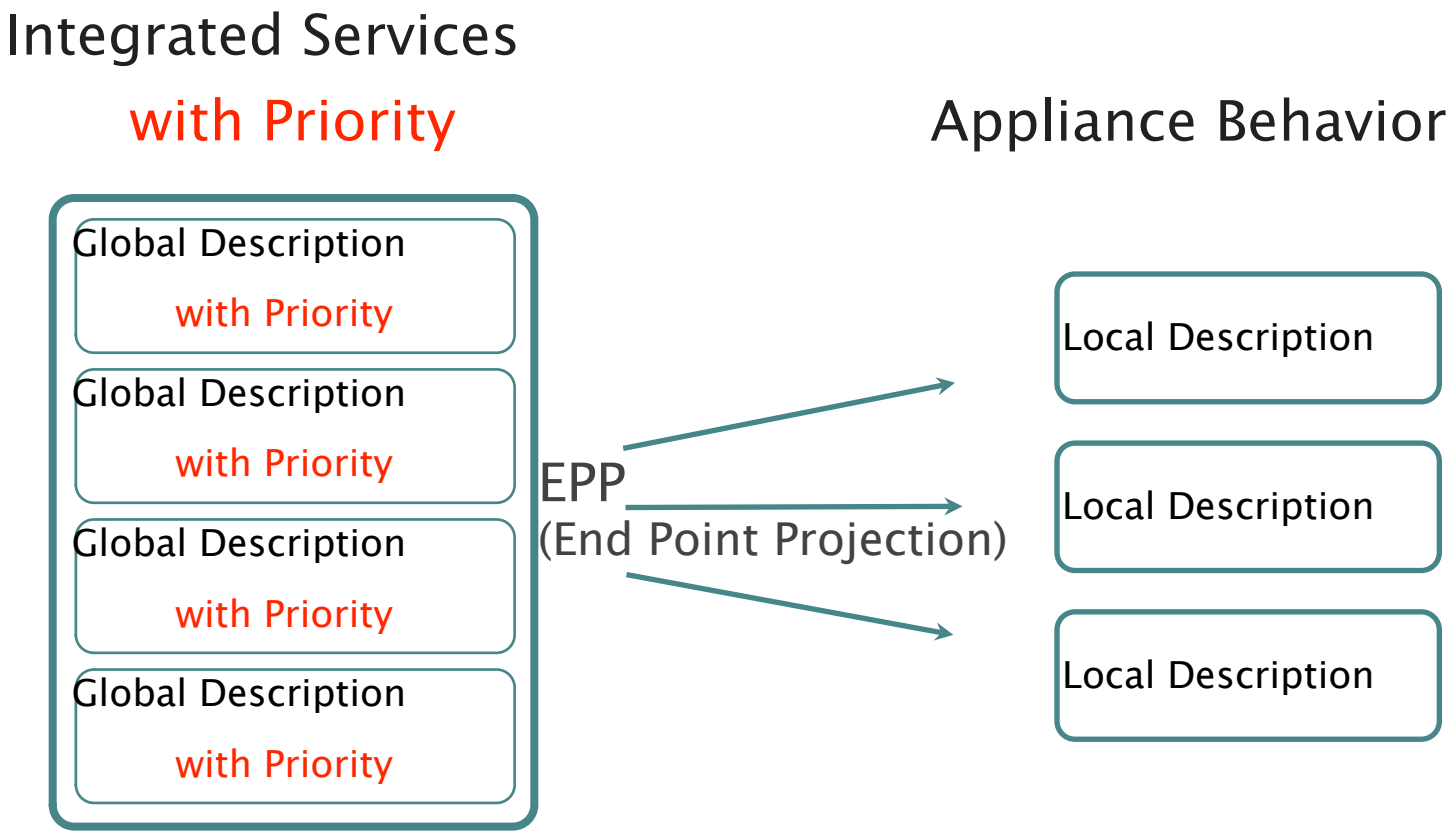

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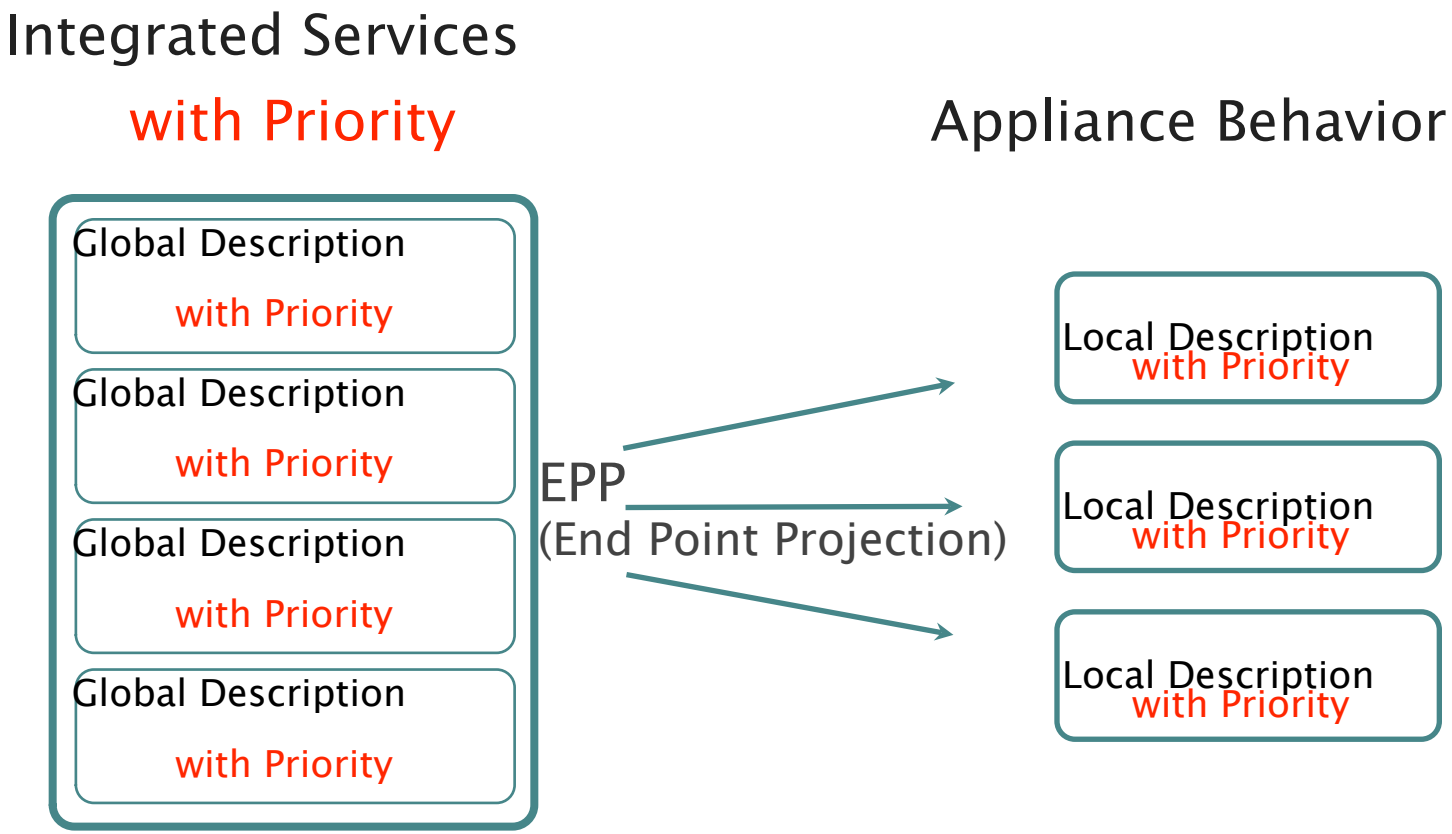

Global Description with Priority

- Priority Altering Operator

Σpmap P ...maps the priority to all interactions in the service

- For a binary case where services P includes I1 and I2
  - ☑ pmap(I1) = p1
  - ☑ pmap(I2) = p2

We write as

I1 p1+p2 I2

for binary choice

- An example for DVD Service

DVD Service[
  DVD Play Interaction
  p1 + p3
  DVD Stop Interaction
]

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LIGHT1 → CURTAIN1 : chCURTAIN1 (vvDVD).
USER → DVD : chDVD (vs'DVD).
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recX.(
USER → DVD : sDVD<play>.
DVD → TV : tDVD<video_on>.
TV → LIGHT1 : uDVD<small>.
LIGHT1 → CURTAIN1 : vDVD<down>.X

p1 + p3

USER → DVD : s'DVD<stop>.
DVD → TV : t'DVD<channel on>.
TV → LIGHT1 : u'DVD<on>.
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DVD Service

I1: DVD Play
I2: DVD Stop

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session initialization

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description for DVD play interaction

p1 + p3

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description for DVD play interaction

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description for DVD stop interaction

DVD Service

I1: DVD Play
I2: DVD Stop

Local Description with Priority

- Priority Guard

  ...an idea borrowed from CPG(CCS with priority guards) by Phillips[P'01]

- A priority guard is written as U : a , where U is a set of sessions and operations

  ☑ communication "a" can be executed if no operator in U is executed at that time

Example for Local Description

LIGHT1[

$ch_{LIGHT1}(u_{DVD}, TV).\ ch_{CURTAIN1}(v_{DVD}, LIGHT1).\ v_{DVD} \triangleleft ack.\ u_{DVD} \triangleright ack.$

$ch_{LIGHT1}(u'_{DVD}, TV).\ ch_{CURTAIN1}(v'_{DVD}, LIGHT1).\ v'_{DVD} \triangleleft ack.\ u'_{DVD} \triangleright ack.$

$ch_{LIGHT1}(u_{IO}, AIR\_CON).\ ch_{PHONE}(v_{IO}, LIGHT1).\ v_{IO} \triangleleft ack.\ u_{IO} \triangleright ack.$

$ch_{LIGHT1}(t'_{DAY}, LIGHTG).\ ch_{LIGHT2}(u'_{DAY}, LIGHT1).\ u'_{DAY} \triangleleft ack.\ t'_{DAY} \triangleright ack.$

recX.(

$u_{DVD} \triangleleft small_{play}.v_{DVD} \triangleright down_{play}.v_{DVD} \triangleleft ack.\ u_{DVD} \triangleright ack.\ X$

+

$u'_{DVD} \triangleleft on_{stop}.v'_{DVD} \triangleright up_{stop}.v'_{DVD} \triangleleft ack.\ u'_{DVD} \triangleright ack.\ X$

+

$(u_{DVD}, small_{play}) : u_{IO} \triangleleft on_{in}.v_{IO} \triangleright on_{in}.v_{IO} \triangleleft ack.\ u_{IO} \triangleright ack.\ X$

+

$(u_{DVD}, small_{play}) : t'_{DAY} \triangleleft on_{even}.u'_{DAY} \triangleright on_{even}.\ u'_{DAY} \triangleleft ack.\ t'_{DAY} \triangleright ack.\ X$)

Example for Local Description

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Example for Local Description

LIGHT1[

$ch_{LIGHT1}(u_{DVD}, TV).\ ch_{CURTAIN1}(v_{DVD}, LIGHT1).\ v_{DVD} \triangleleft ack.\ u_{DVD} \triangleright ack.$

$ch_{LIGHT1}(u'_{DVD}, TV).\ ch_{CURTAIN1}(v'_{DVD}, LIGHT1).\ v'_{DVD} \triangleleft ack.\ u'_{DVD} \triangleright ack.$

$ch_{LIGHT1}(u_{IO}, AIR\_CON).\ ch_{PHONE}(v_{IO}, LIGHT1).\ v_{IO} \triangleleft ack.\ u_{IO} \triangleright ack.$

$ch_{LIGHT1}(t'_{DAY}, LIGHTG).\ ch_{LIGHT2}(u'_{DAY}, LIGHT1).\ u'_{DAY} \triangleleft ack.\ t'_{DAY} \triangleright ack.$

recX.(

$u_{DVD} \triangleleft small_{play}.v_{DVD} \triangleright down_{play}.v_{DVD} \triangleleft ack.\ u_{DVD} \triangleright ack.\ X$

DVD Play Interaction

+

$u'_{DVD} \triangleleft on_{stop}.v'_{DVD} \triangleright up_{stop}.v'_{DVD} \triangleleft ack.\ u'_{DVD} \triangleright ack.\ X$

DVD Stop Interaction

+

$(u_{DVD}, small_{play}) : u_{IO} \triangleleft on_{in}.v_{IO} \triangleright on_{in}.v_{IO} \triangleleft ack.\ u_{IO} \triangleright ack.\ X$

Coming Home Interaction

+

$(u_{DVD}, small_{play}) : t'_{DAY} \triangleleft on_{even}.u'_{DAY} \triangleright on_{even}.\ u'_{DAY} \triangleleft ack.\ t'_{DAY} \triangleright ack.\ X$)

Evening Interaction

Example for Local Description

LIGHT1[

$ch_{LIGHT1}(u_{DVD}, TV).\ ch_{CURTAIN1}(v_{DVD}, LIGHT1).\ v_{DVD} \triangleleft ack.\ u_{DVD} \triangleright ack.$

$ch_{LIGHT1}(u'_{DVD}, TV).\ ch_{CURTAIN1}(v'_{DVD}, LIGHT1).\ v'_{DVD} \triangleleft ack.\ u'_{DVD} \triangleright ack.$

$ch_{LIGHT1}(u_{IO}, AIR\_CON).\ ch_{PHONE}(v_{IO}, LIGHT1).\ v_{IO} \triangleleft ack.\ u_{IO} \triangleright ack.$

$ch_{LIGHT1}(t'_{DAY}, LIGHTG).\ ch_{LIGHT2}(u'_{DAY}, LIGHT1).\ u'_{DAY} \triangleleft ack.\ t'_{DAY} \triangleright ack.$

recX.(

$u_{DVD} \triangleleft small_{play}.v_{DVD} \triangleright down_{play}.v_{DVD} \triangleleft ack.\ u_{DVD} \triangleright ack.\ X$

DVD Play Interaction

+

$u'_{DVD} \triangleleft on_{stop}.v'_{DVD} \triangleright up_{stop}.v'_{DVD} \triangleleft ack.\ u'_{DVD} \triangleright ack.\ X$

DVD Stop Interaction

+

$(u_{DVD}, small_{play}) : u_{IO} \triangleleft on_{in}.v_{IO} \triangleright on_{in}.v_{IO} \triangleleft ack.\ u_{IO} \triangleright ack.\ X$

Coming Home Interaction

+

$(u_{DVD}, small_{play}) : t'_{DAY} \triangleleft on_{even}.u'_{DAY} \triangleright on_{even}.\ u'_{DAY} \triangleleft ack.\ t'_{DAY} \triangleright ack.\ X\ )$

Evening Interaction

Priority Guard

LIGHT1 can execute the coming home interaction only if the operator $small_{play}$ in the priority guard is not executing at that time

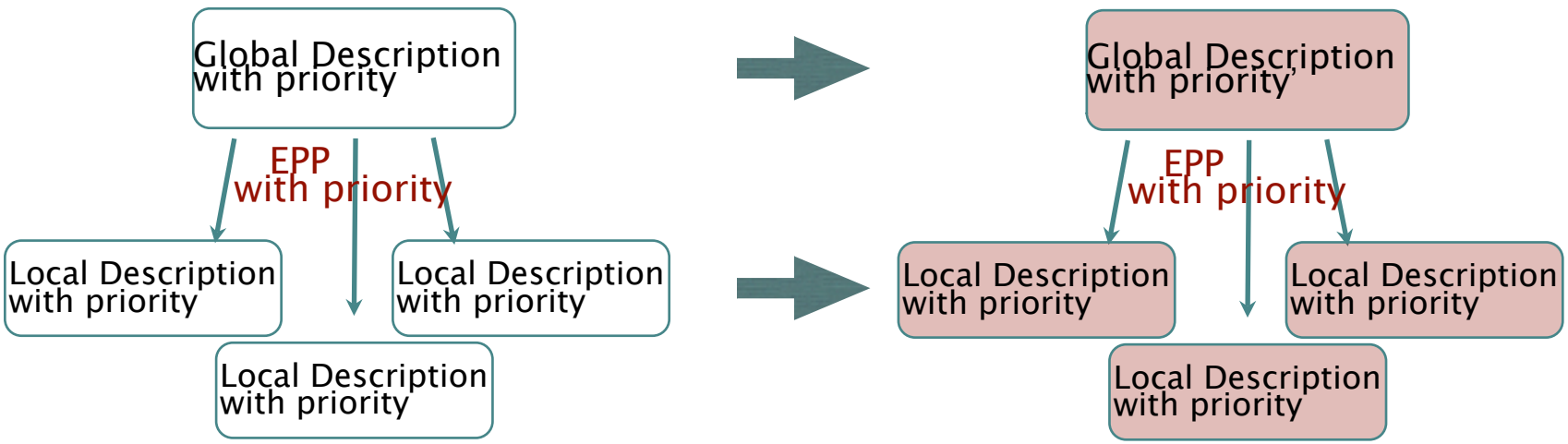
EPP with Priority

- Several examples of interactions
  - ☑ Based the equivalence of global and local descriptions
  - ☑ EPP fits with the descriptions with priority

EPP with Priority

- Several examples of interactions
  - ☑ Based the equivalence of global and local descriptions
  - ☑ EPP fits with the descriptions with priority

☑ Each step of the global description corresponds to that of the local descriptions derived from the global descriptions



Remarks

- Fine-grained controls by communication with priority
  → extend the existing framework for web services
- EPP as a foundation for compositional development
  for distributed systems
- Application to home appliance network with priority
- Global description is simple (Guraded/Regular)

Future Directions

- Timed process calculi with EPP
- Application to larger examples (Automotive software)
- General theory of EPP with time/priority
- Interrupts / Exceptions