Modular Verification of Web Services Using Efficient Symbolic Encoding and Summarization

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Motivation

- Increasing interest in web-based business management involving inter-organizational interactions and critical transactions

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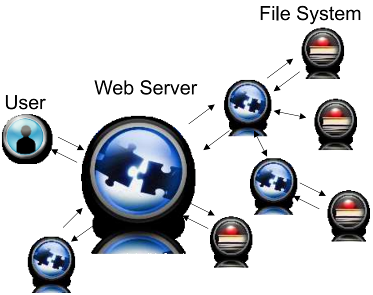
- Web services provide mechanisms implementing such applications
- Need formal mechanisms to ensure that web services behave properly
- We propose an automatic verification tool featuring efficient symbolic encoding and modular verification using summarization

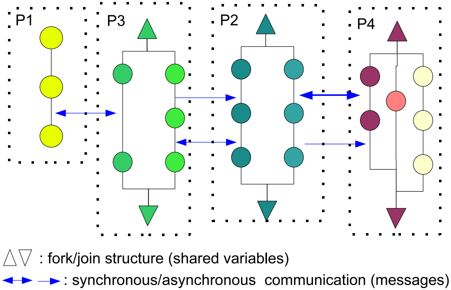
Web Services

- Interoperable Machine to Machine software
- Some Industry Standards: Business Process Execution Language (BPEL), Web Service Description Language (WSDL)



BPEL Web Services

A distributed system with both multi-threading (internal) and message-passing (external).



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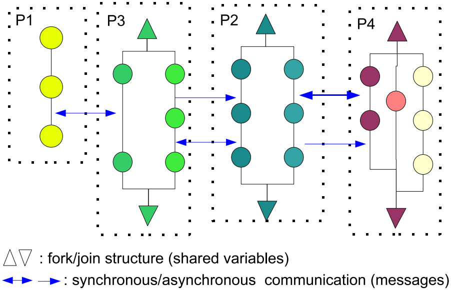
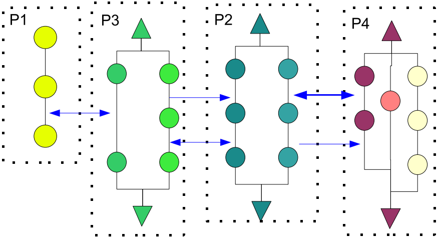
- *flow* activities $\Rightarrow$ fork/join structure



BPEL Web Services

A distributed system with both multi-threading (internal) and message-passing (external).

- *flow* activities ⇒ fork/join structure
- *invoke*, *receive*, *reply* activities ⇒ asynchronous/synchronous communications

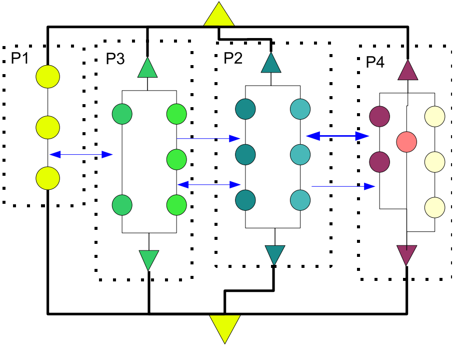


△▽ : fork/join structure (shared variables)

↔ → : synchronous/asynchronous communication (messages)

Monolithic Analysis

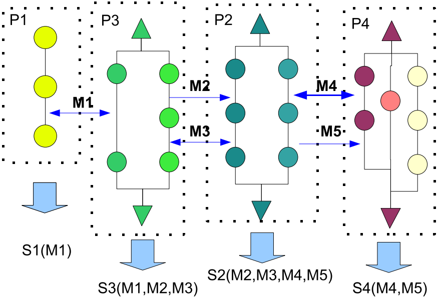
- Consider all of them as one composite service by adding a outer fork/join structure
- Need to consider all interleavings among threads
- Suffer from state explosion problem



Modular Verification

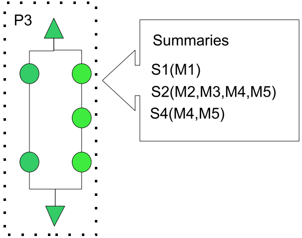
From processes to summaries.

- Interference among processes is limited to the values of messages
- Summarize processes on messages



Modular Verification

- Modular Analysis: check one process within which interactions among other processes are patched by their summaries



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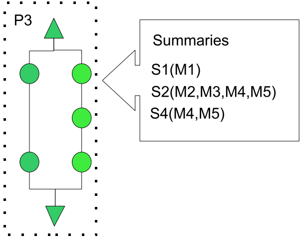
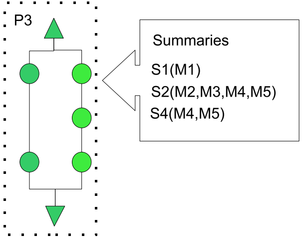
- From $P_1 \times \ldots \times P_n$ to $P_1 + \ldots + P_n$

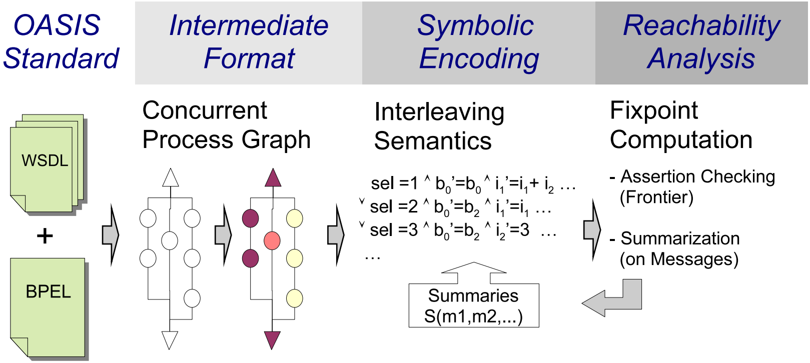


Modular Verification

- Modular Analysis: check one process within which interactions among other processes are patched by their summaries
- From $P_1 \times \ldots \times P_n$ to $P_1 + \ldots + P_n$
- No precision loss with respect to assertion checking within processes



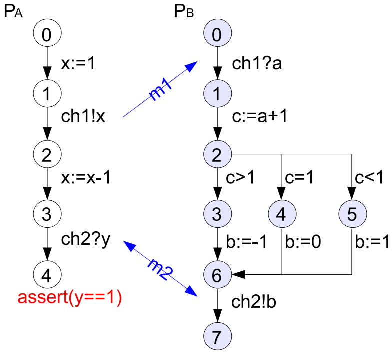
Our Framework



Summarization: A Simple Example

Consider the following two concurrent processes.

- P_A invokes P_B
- An assertion within P_A at node 4



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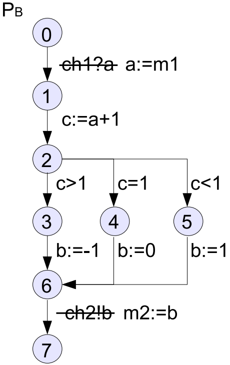
- Compute the forward fixpoint of reachable states
- Project the fixpoint to input and output messages (using existential quantifier elimination)

Summarize Process Behavior: A Simple Example

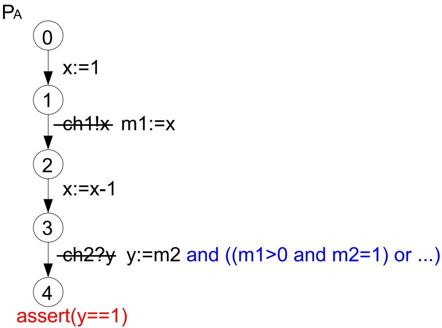


The summary of P_B is:

$$(m_1 > 0 \wedge m_2 = 1) \vee$$
$$(m_1 = 0 \wedge m_2 = 0) \vee$$
$$(m_1 < 0 \wedge m_2 = -1)$$

Compose Summaries: A Simple Example

- Compose summaries by conjoining the summaries of other processes with the receive activities



Compose Summaries: A Simple Example

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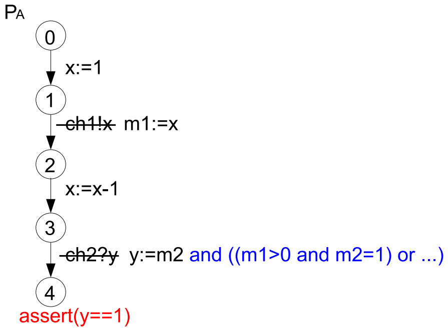
- One can prove P_A's assertion modularly



Modularity of Processes

An assertion can be proven via modular analysis if and only if it can be proven via monolithic analysis.

- T: transition relation, I: initial states, X: variables
- $reach(T, I)$ returns the fixpoint of reachable states
- The insight comes from the property:

$$reach(T, I(C) \wedge I(X)) \equiv I(C) \wedge reach(T, I(X))$$

if $C \subseteq X$ are parameterized constants (not defined in T).

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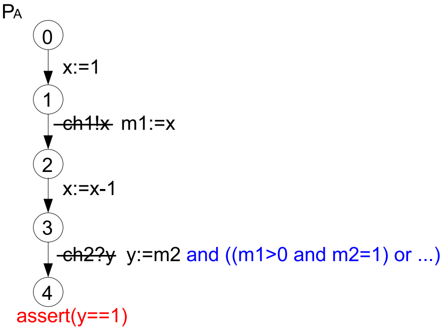
- From the receiver's perspective, a message is a parameterized constant
- One can summarize the receiver's behavior ($reach(T, I(X))$) without knowing the states of its input messages ($I(C)$)
- One can compute the precise reachable states of the receiver's output messages ($reach(T, I(C) \wedge I(X))$) by conjoining
  - the states of the receiver's input messages ($I(C)$) and
  - the receiver's summary ($reach(T, I(X))$)

Modularity of Processes: A Simple Example

- The state of m_1 is initialized upon sending and is imposed implicitly after sending



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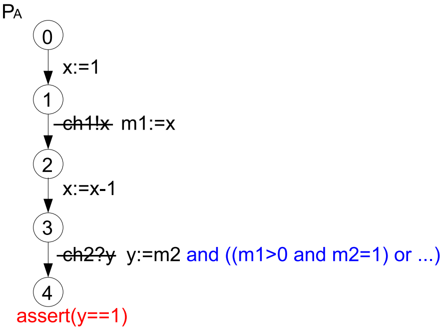
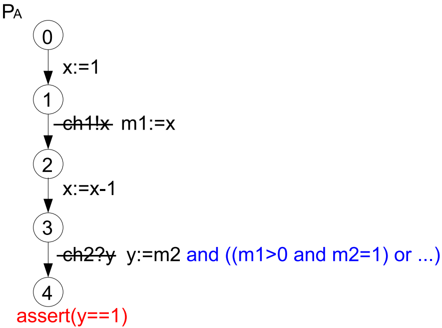
- The summary of P_B (the relation among m_1 and m_2) is conjoined upon receiving



Modularity of Processes: A Simple Example

- The state of m_1 is initialized upon sending and is imposed implicitly after sending
- The summary of P_B (the relation among m_1 and m_2) is conjoined upon receiving
- P_A gets the precise reachable states of m_2 ($m_2 = 1$).



Restrictions

- We assume that each channel is associated with precisely one send activity and one receive activity
- The examples we analyzed do not violate this condition
- For the specifications which violate this condition:
  - Rename channels if multiple send/receive pairs use the same channel
  - If there is a send or receive activity within a loop, unwind the loop a fixed number of times

Efficient Assertion Checking

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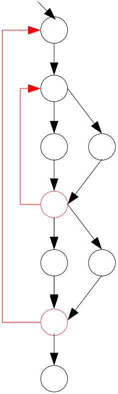
- I: initial states, T: transition relation, Err: risk states (violate assertions)
- $F^0 = I$ and $F^i = post(T, F^{i-1}) \setminus F^{i-1}$
- Assertion violated at the i^{th} iteration when $F^i \cap Err \neq \emptyset$

Termination Condition

- When the CPG is acyclic,
  - No back edges
  - Terminate when F^i is empty



Termination Condition

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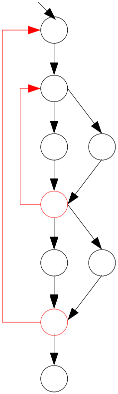
- When the CPG is not acyclic,
  - Compute S_{back}, the states associated with the source nodes of the back edges (much smaller than the universe)
  - At each iteration, compute R_{back}, the set of reached states fall in S_{back}
  - Terminate when $F^i \setminus R_{back}$ is empty



The Assertion Checking Algorithm

Reach_frontier(T,I,Err,S_{back})

- $F = I$;
- $R_{back} = I \cap S_{back}$;

$false$ - assertion violated. $true$ - assertion proven.

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Experiment: Loan Approval

	Monolithic Verification	Modular Verification			
	All	Approval	Assessor	Approver	Customer
Result	P	P	S	S	S
Time (s)	1227.2	124.5	0.1	0.1	0.1
Memory (MB)	810	490	289	290	290
ITRs	32	16	10	10	5

- Customer invokes Approval which invokes Assessor and Approver
- Result: NA-did not terminate, P-passed assertion checks, S-summarized
- ITRs: the number of iterations of the fixpoint computation

Experiment: Travel Agency

	Monolithic Verification	Modular Verification			
	All	VTA	Hotel	Flight	User
Result	NA	P	S	S	S
Time (s)	18947	814	13.5	13.4	34.6
Memory (MB)	1663	363	273	363	284
ITRs	57	55	23	22	30

- User invokes VTA which invokes Hotel and Flight
- Result: NA-did not terminate, P-passed assertion checks, S-summarized
- ITRs: the number of iterations of the fixpoint computation

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- We propose modular verification for message-passing processes to achieve scalability
- We propose an efficient symbolic encoding and reachability analysis to facilitate our approach
- We have implemented a prototype tool that can automatically analyze web services specified in BPEL+WSDL

Related Work

- BPEL Verification:
  - Safety property [Foster et al. ICWS04] [Lohmannet et al. BPM06]
  - LTL property [Fu et al. WWW04] [Nakajima ENTCS06]
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- Compositional Reasoning:
  - LTSA [Cobleigh et al. TACAS03]
  - Magic/Comfort [Chaki et al. FMSD04] [Sharygina et al. CAV05]

Thank you. Any Questions?