A Formal Approach for Run-Time Verification of Web Applications using Scope-Extended LTL

May Haydar

Supervisor: Prof. Houari Sahraoui

MoSART

June 19, 2008

Université de Montréal

CRIM

Outline

- Motivation
- Problem Statement
- Formal Modeling of Web Applications
- Extending LTL with Propositional Scopes
- Implementation and Evaluation
- Conclusions and Future Work

Motivation

- Steep and radical growth of web applications

  n-tiered applications, diverse types of users, increasingly complex and critical to everyday life

- Existing tools test various aspects of web applications
  - HTML syntax (HTML TIDY), Hyperlink integrity (LinkCheck)
  - Java code testing (JCover), Performance (MSACT)

- Principle limitation of existing tools is their incapability of verifying properties in executions of WAs

- Need for analysis and validation methods and tools to ensure high quality of web applications

- Formal methods are increasingly used in system verification

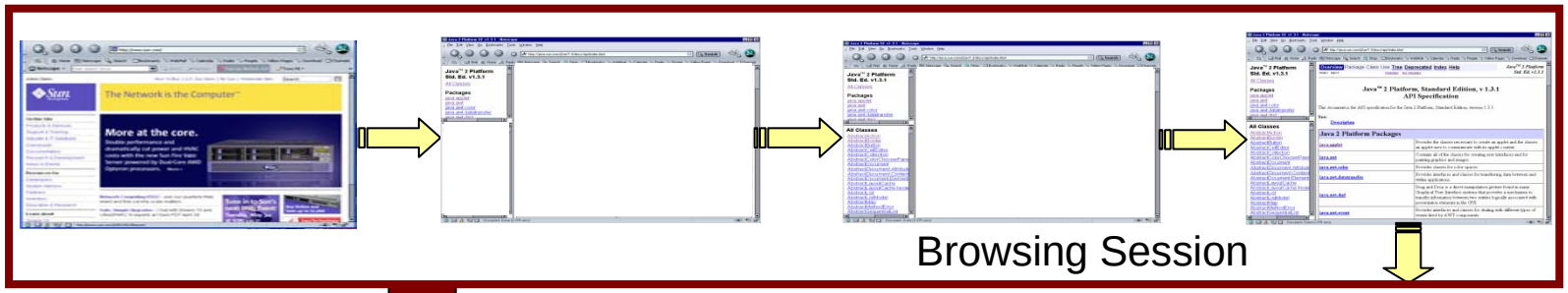
Problem Statement and Solution

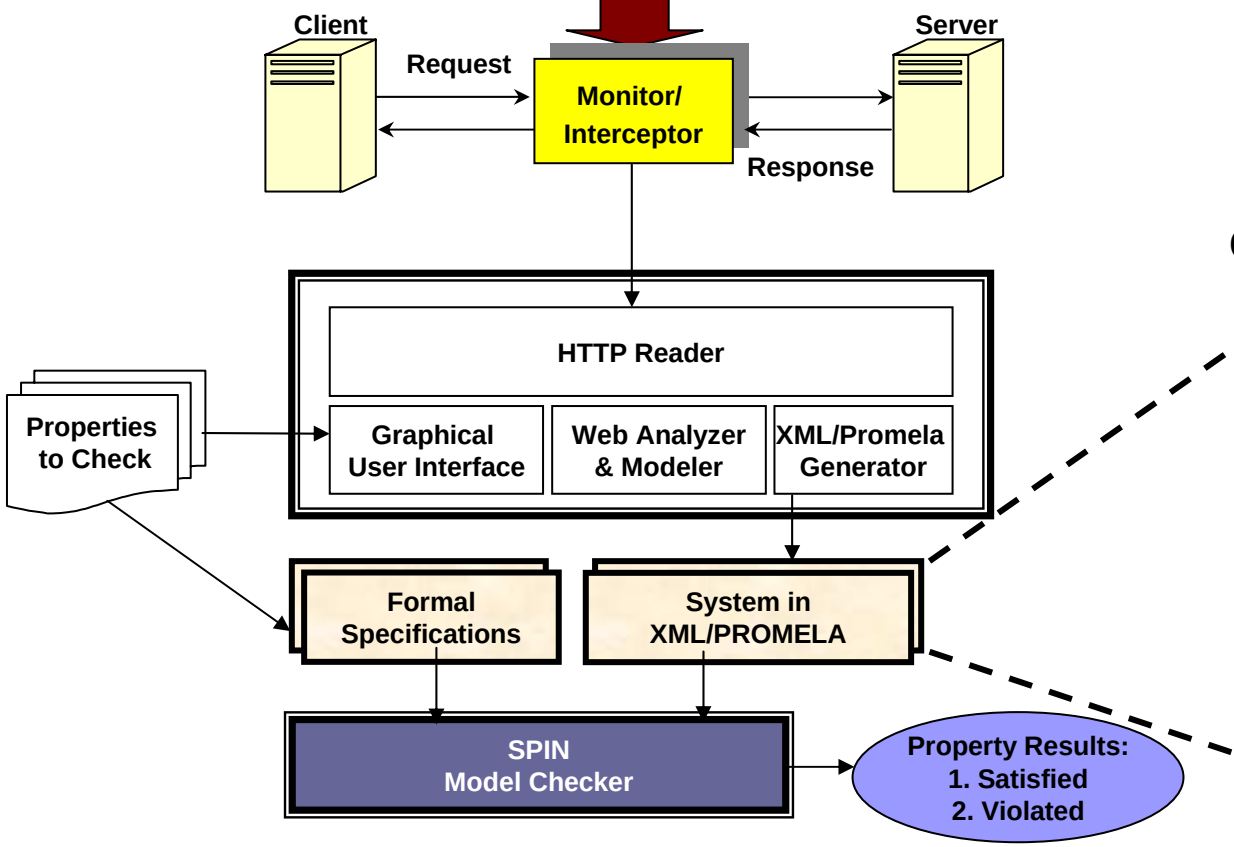
- Given a Web Application Under Test (WAUT) with no access to the code
  - Define properties related to specifications of web applications
  - Verify whether the WAUT satisfies the properties

- Solution
  - Infer automata based models from WAUT
  - Build library of user defined properties

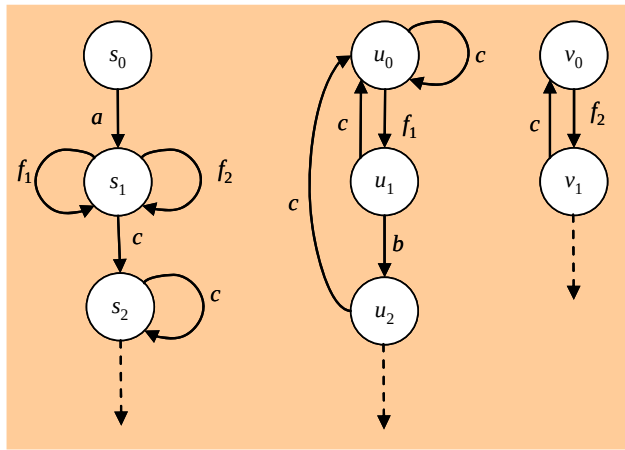
    alleviate the need to learn the foundations of temporal logic for property specification
  - Use of a model checker to verify if the WAUT satisfies properties

Formal Framework





Communicating Automata Model

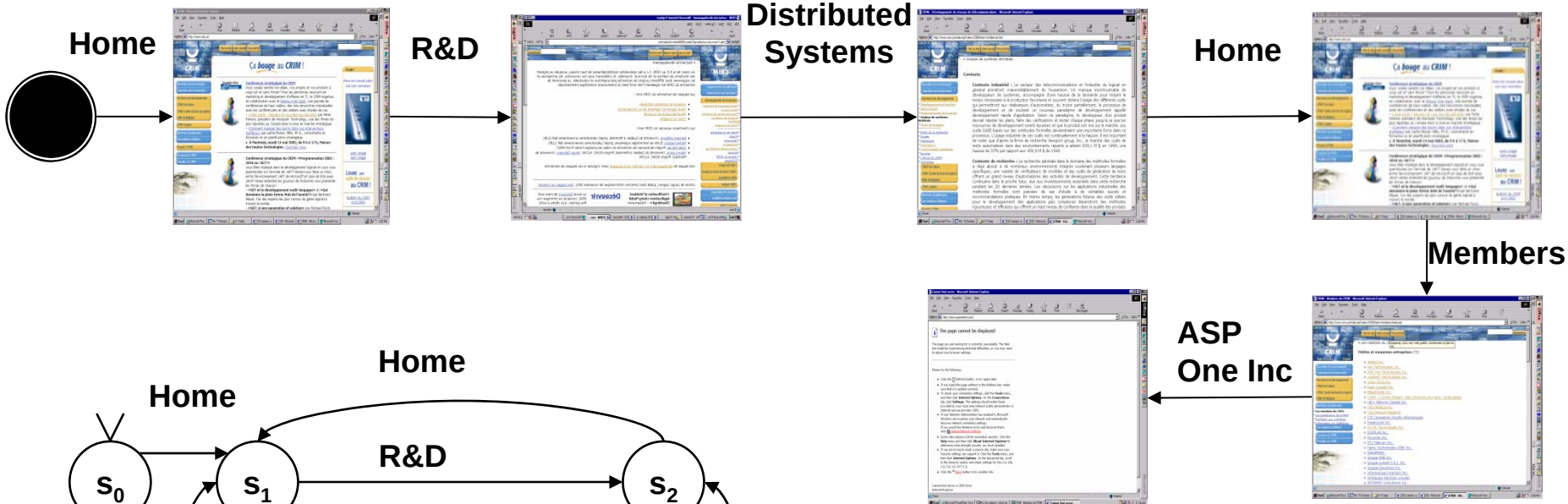


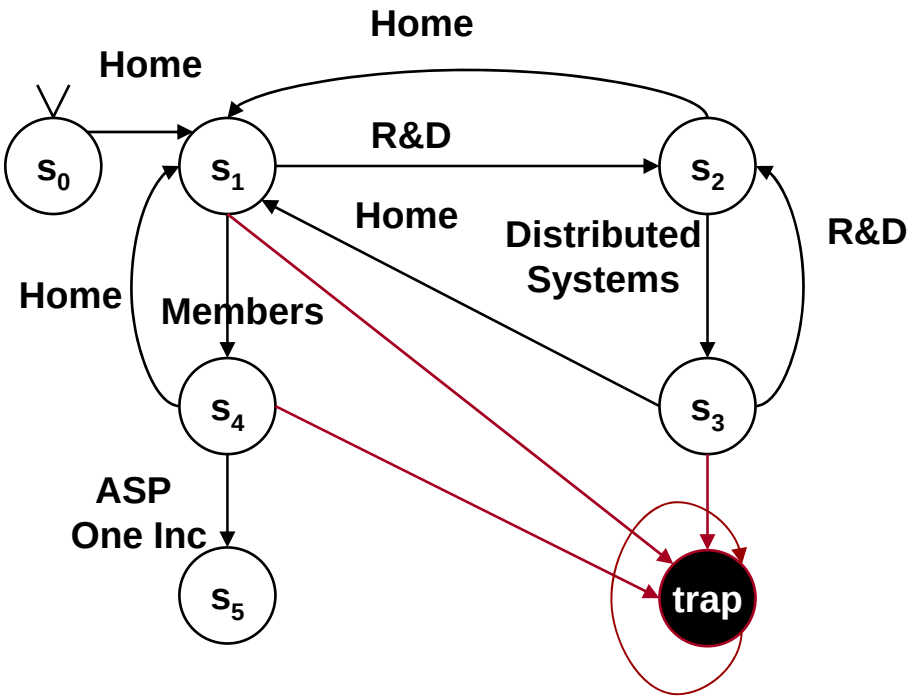
Run-time Observation of WA

- Log a trace of HTTP requests and responses - Request Response Sequence (RRS)
  - Requests for links clicked and forms submitted
  - Responses are HTML content of static/dynamic pages
- Links and forms could be repeated on different pages
- Model a RRS by an automaton

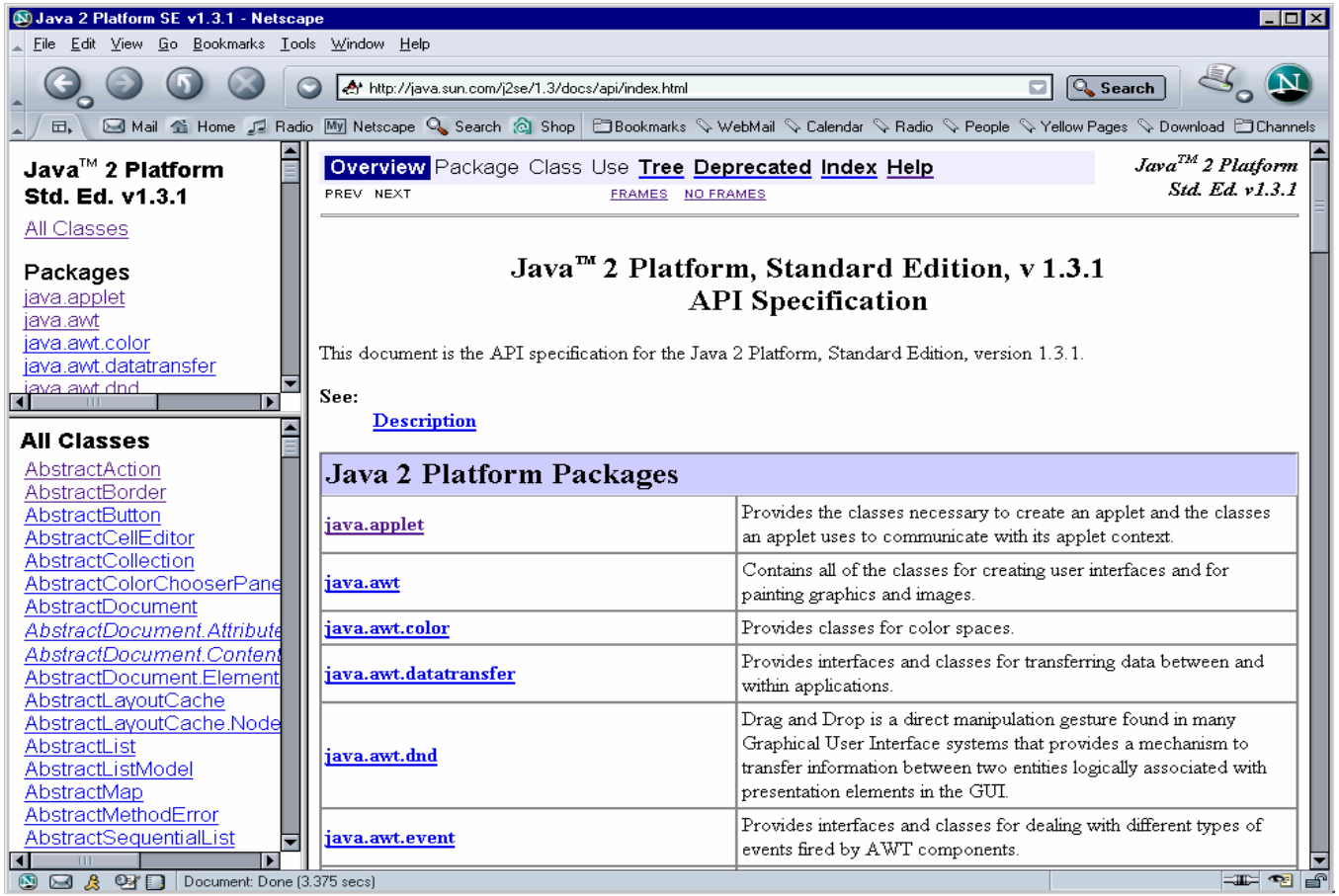
  $A_{RRS} = < S \cup \{trap\}, s_0, \Sigma, T >$ called session automaton

Example


Home
R&D
Distributed Systems
Home
Members
ASP One Inc


Home
Home
R&D
Home
Distributed Systems
R&D
Home
Members
ASP One Inc
s_0
s_1
s_2
s_3
s_4
s_5
trap

Modeling Multi Display WAs

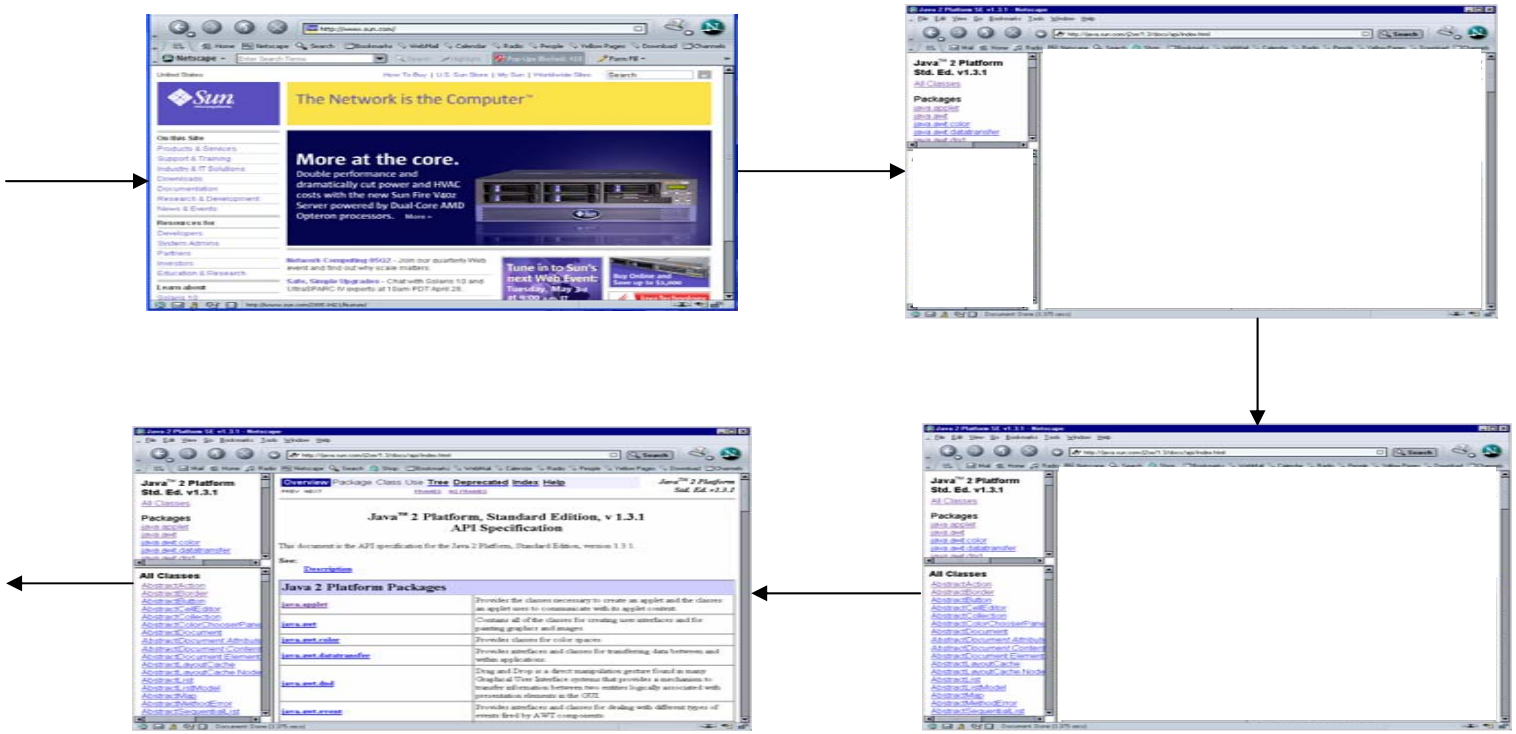


- From browsing session
  - 1 main window, 3 frames
- 4 local sessions

Local Session Communicating Automata

- An automaton represents a window or a frame
- The set of events is extended by URIs of frame source pages
- Rendezvous communication on common events
  - Links and filled forms with targets are common events in automaton of the source and target entities
  - Common events are enabled in all the states of the automata of the target entity

Stable – Transient Displays

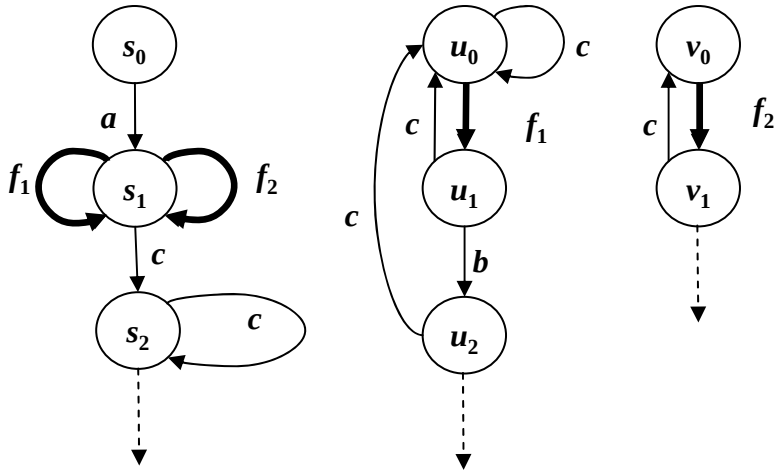


Some properties need to be checked only in stable displays

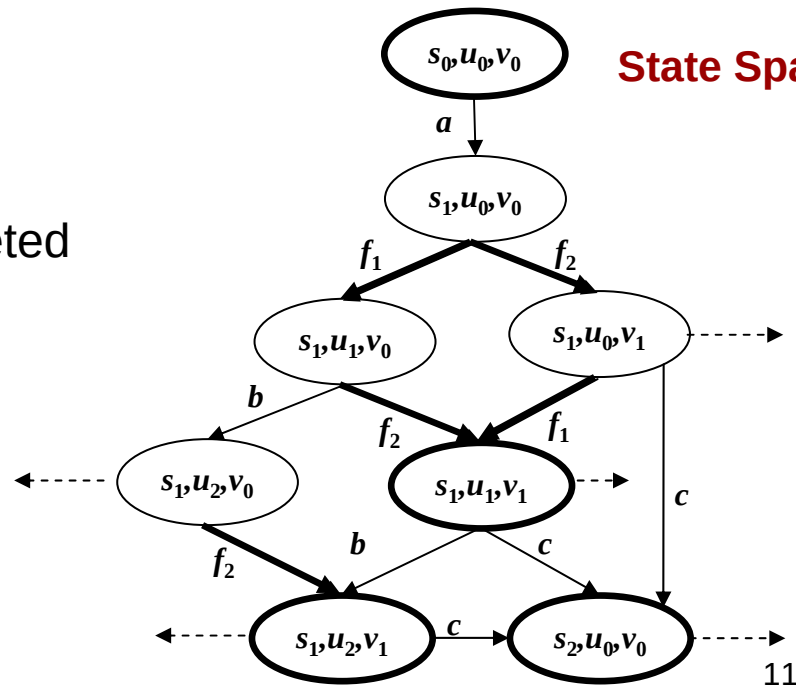
- *An important advertisement should be present in every display shown to the user of a WA with (at least) two frames*
- *The number of links shown to the user should always be greater than a predefined threshold*

Stable – Transient Global States

System Model



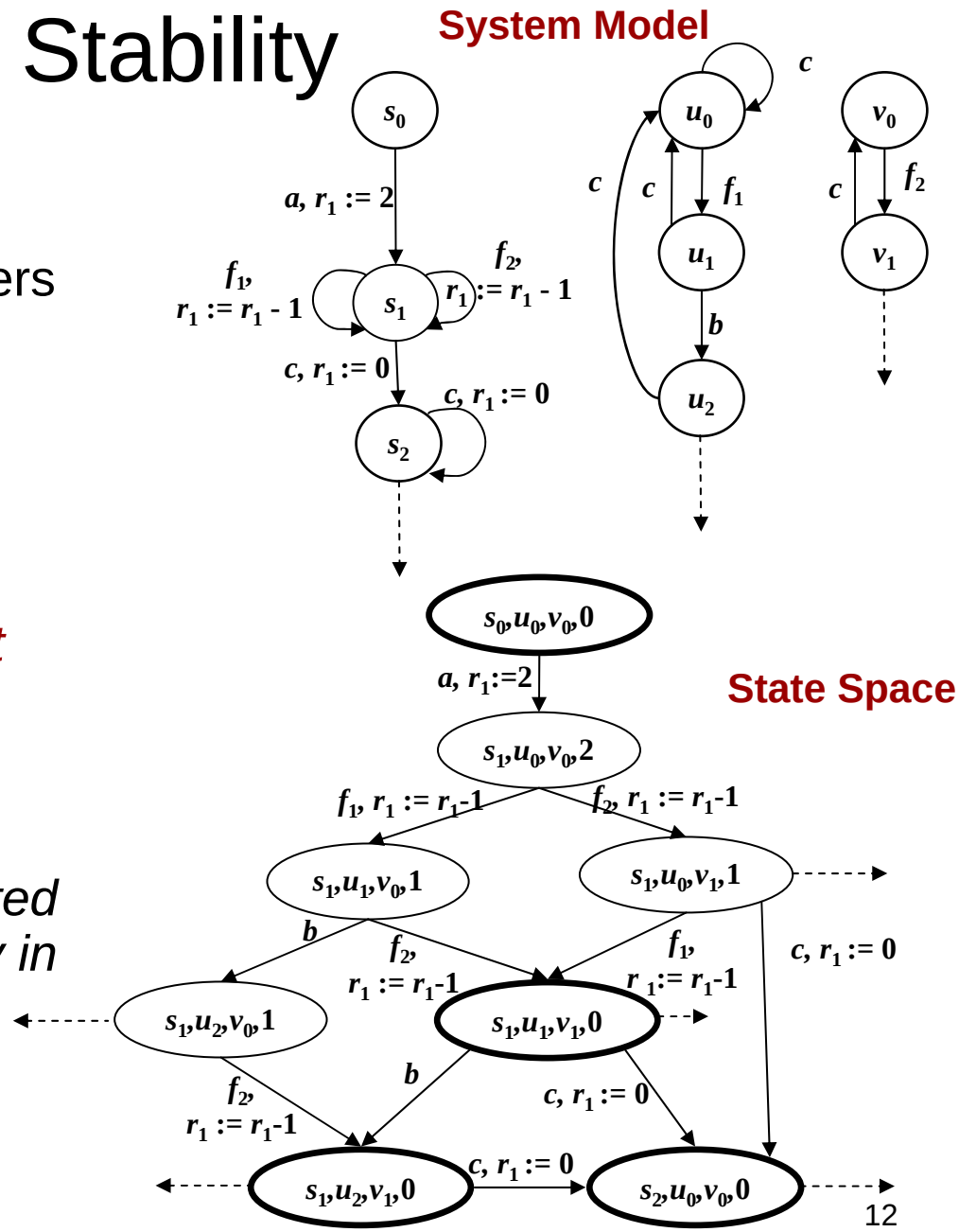
State Space



- In multi display web applications
  - Stable state corresponds to completed display
  - Transient state corresponds to incomplete display
- User actions: links, forms
- Browser actions: URLs of frame default pages

Determining State Stability

- Need for means to distinguish stable and transient states recognizable by model checkers
- Devise generic algorithm to extend the communicating automata with local variables and updates
- Each automaton has an *event tracking* variable to count *designated* events enabled at each state
- *Designated events are executed once ⇒ System does not stay in transient mode*



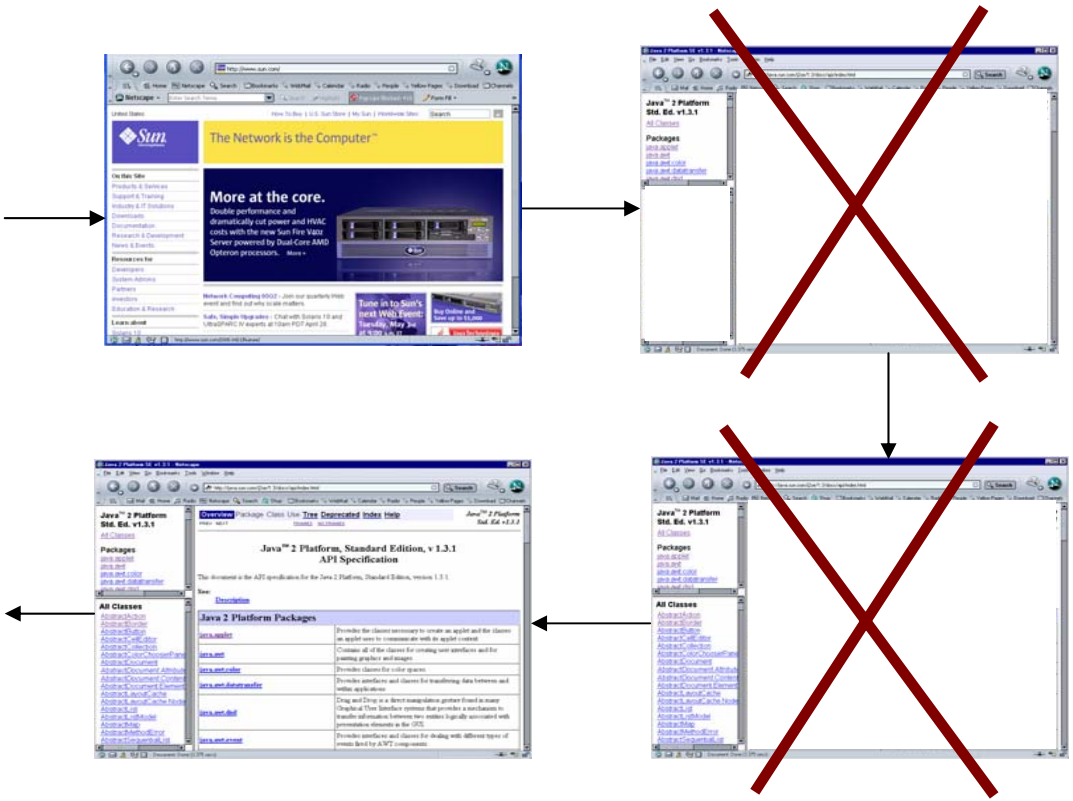
LTL is not Enough

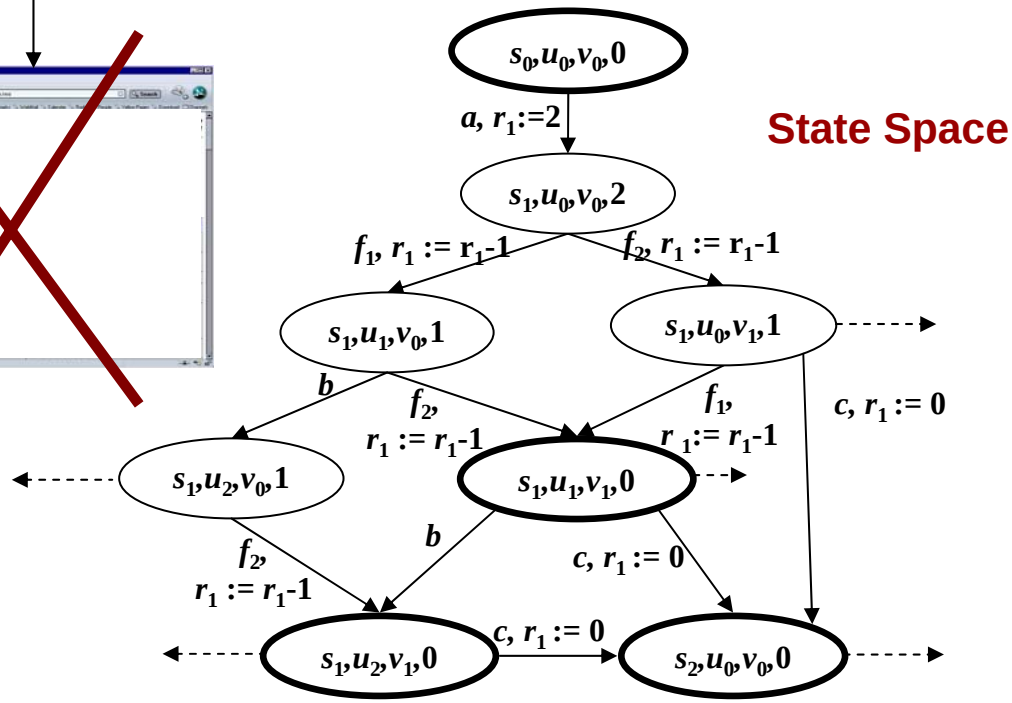
- Specifying properties specification is difficult for novices and professionals
  - Lack of complete specifications
  - Limitations of the language
- Web application model may include states uninteresting to certain properties
- How to specify LTL properties checkable in an arbitrary subset of the state space

Intuitive solution

remove the uninteresting states from the model

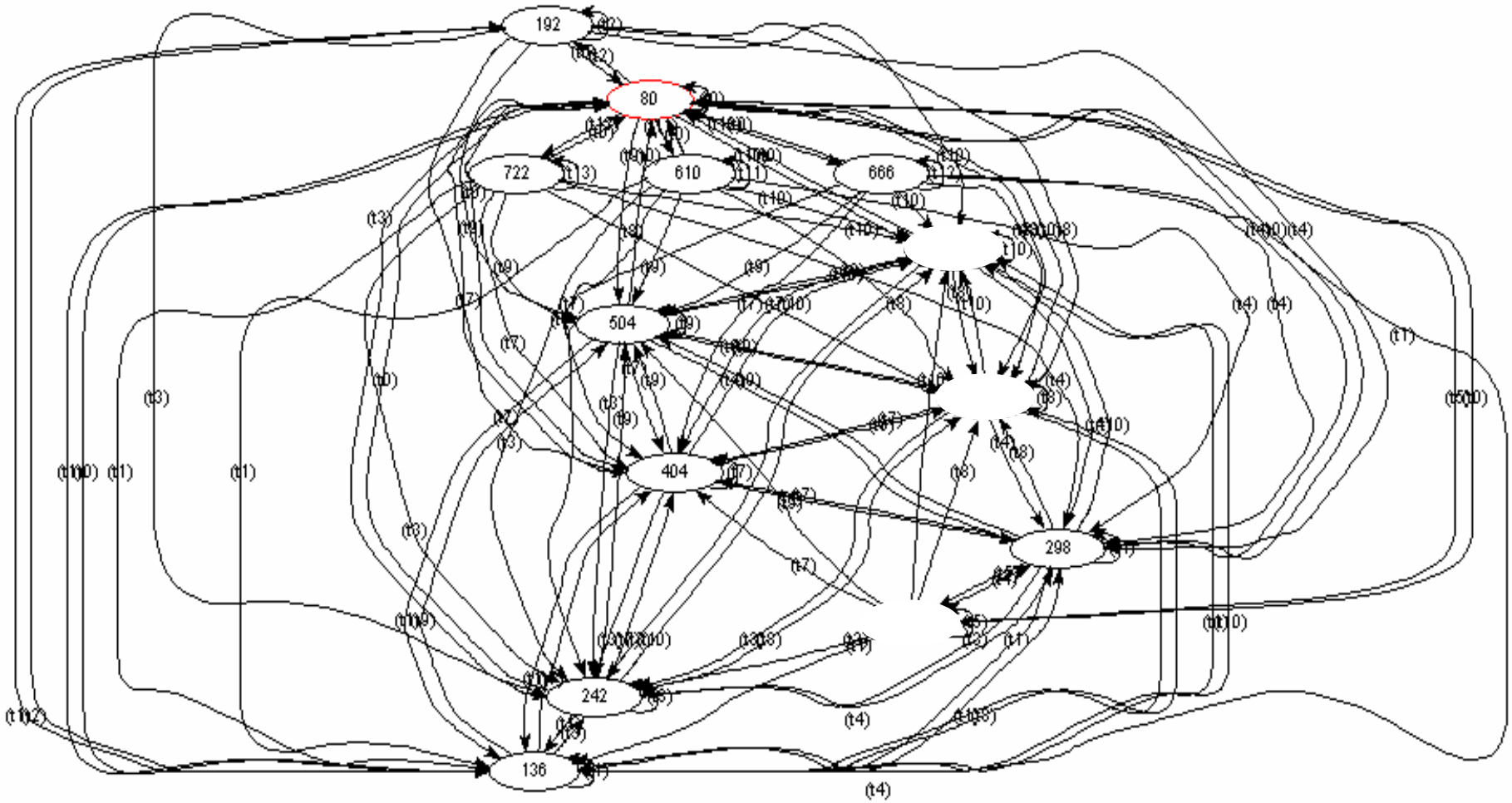
Example





State Space

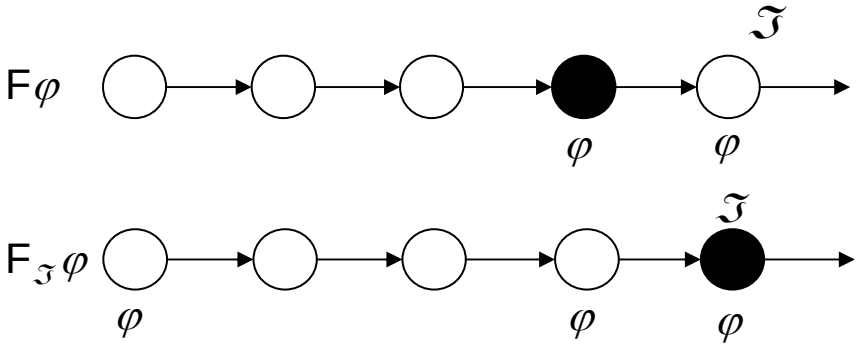
Example

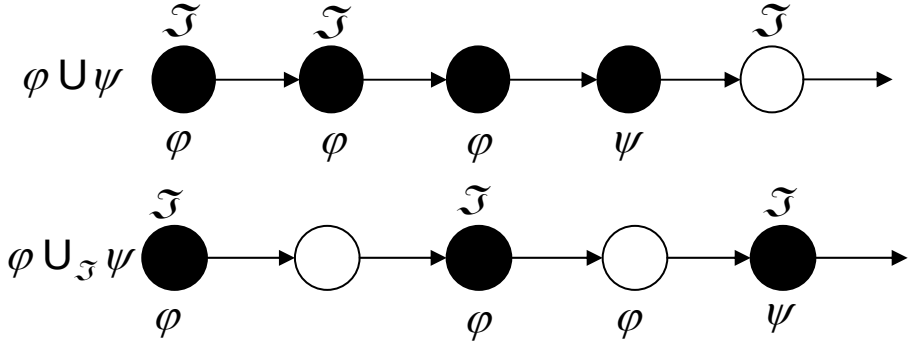


Extending LTL with Scopes

- Define a means to specify LTL properties over arbitrary subsets of the state space
  - Do not add to the complexity of specification
  - Do not modify the model
  - Model checking algorithms still can be used
- Solution
  - Introduce scopes to define subsets of the search state space
  - Add new operators to LTL to check properties within defined scopes
- Result in succinct formulae

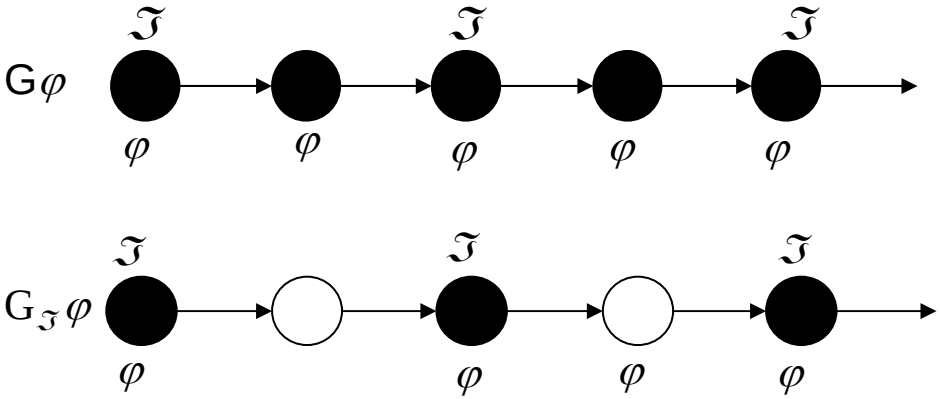
LTL with Propositional Scopes

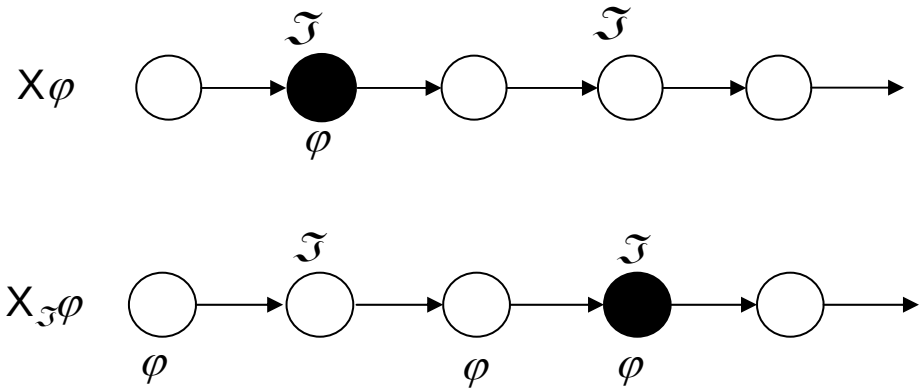




$F_{\mathfrak{J}}\,\varphi = F\,(\varphi \wedge \mathfrak{J})$

$\varphi\,U_{\mathfrak{J}}\,\psi = (\mathfrak{J} \rightarrow \varphi)\,U\,(\psi \wedge \mathfrak{J})$





$G_{\mathfrak{J}}\,\varphi = G\,(\mathfrak{J} \rightarrow \varphi)$

$X_{\mathfrak{J}}\,\varphi = \neg\mathfrak{J}\,U\,[\mathfrak{J} \wedge X\,(\neg\mathfrak{J}\,U\,(\mathfrak{J} \wedge \varphi))]$

Scope Operator **In**

- Recursively applies propositional scope on any formula
- Makes property specification intuitive and succinct

p **In** $\mathfrak{I} = \neg\mathfrak{I}\ \mathsf{U}\ (p \wedge \mathfrak{I})$

$(\neg\varphi)$ **In** $\mathfrak{I} = \neg_{\mathfrak{I}}(\varphi$ **In** $\mathfrak{I})$

$(\varphi \wedge \psi)$ **In** $\mathfrak{I} = (\varphi$ **In** $\mathfrak{I}) \wedge_{\mathfrak{I}} (\psi$ **In** $\mathfrak{I})$

$(\varphi\ \mathsf{U}\ \psi)$ **In** $\mathfrak{I} = (\varphi$ **In** $\mathfrak{I})$ **In** $_{\mathfrak{I}}(\psi$ **In** $\mathfrak{I})$

$(\mathsf{G}\ \varphi)$ **In** $\mathfrak{I} = \mathsf{G}_{\mathfrak{I}}(\varphi$ **In** $\mathfrak{I})$

$(\mathsf{F}\ \varphi)$ **In** $\mathfrak{I} = \mathsf{F}_{\mathfrak{I}}(\varphi$ **In** $\mathfrak{I})$

$(\mathsf{X}\ \varphi)$ **In** $\mathfrak{I} = \mathsf{X}_{\mathfrak{I}}(\varphi$ **In** $\mathfrak{I})$

Example

The user accesses a Secure page only twice and each time after a visit to Authentication page

- Standard LTL

  $(\neg Authentication \wedge \neg Secure)\ U\ (Authentication \wedge \neg\ Secure \wedge X\ (\neg\ Secure\ U\ (Secure \wedge \neg\ Authentication \wedge X\ (\neg\ Authentication\ U\ (Authentication \wedge \neg\ Secure \wedge X\ (\neg\ Secure\ U\ (Secure \wedge \neg\ Authentication \wedge X\ (\neg\ Authentication\ U\ (Authentication \wedge \neg\ Secure \wedge X\ (G\ (\neg\ Secure)))))))))$

- Using **`In`** operator
  - Scope is $(Authentication \oplus Secure)$ where $\oplus$ is the exclusive or operator
  - $Authentication \wedge X(Secure \wedge X(Authentication \wedge X(Secure \wedge X(Authentication \wedge G(\neg\ Secure)))))$ **`In`** $(Authentication + Secure)$

WeSPaS - Web Specification Pattern System

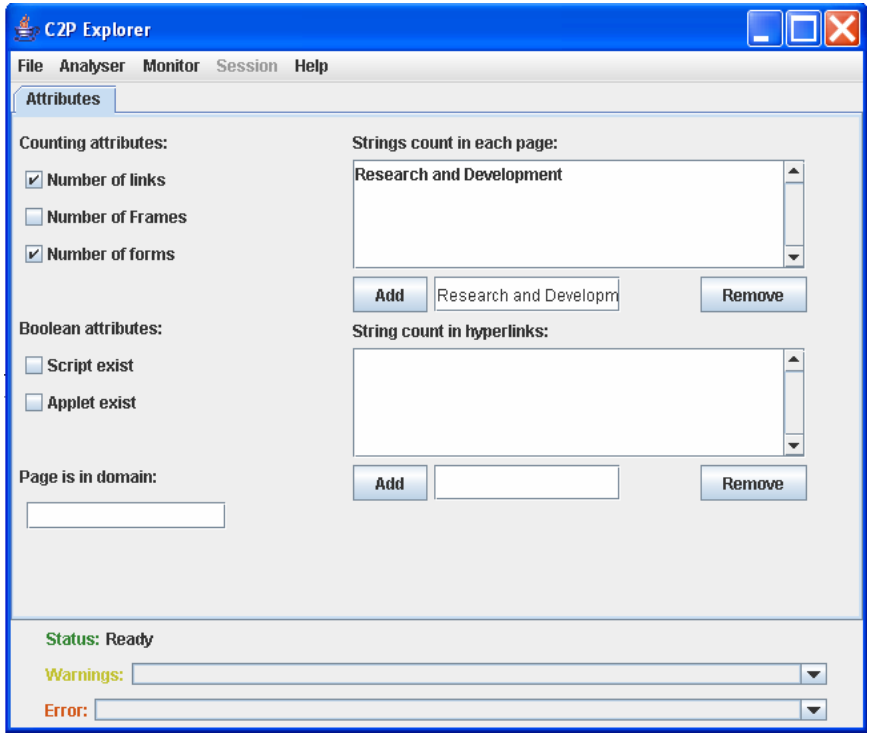
- Common web quality attributes include
  - Reliability and functionality, Usability, Security and privacy
- Survey of various resources: IBM, Opquast (Temesis), literature, Ph.D. work within GEODES (Ghazwa Malak)
- Identified *Custom* attribute related to stakeholders needs

  Incorrect login is allowed only three times in a row, and then login is forbidden
- Categorization (118 patterns)
  - Non-functional: Navigation and Links – Presentation and Content
  - Functional
    - Reachability
    - Security/Authentication and Trust
    - E-commerce (Customer Service –Product Info and Navigation – Purchase Transaction)

Which Properties are Preserved

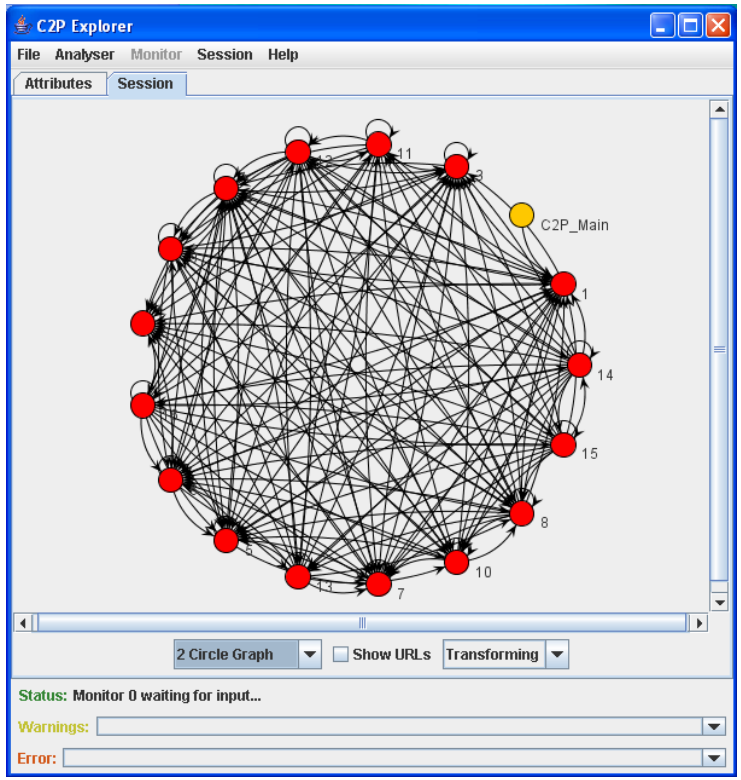
- If a property valid/invalid in session automaton can the same verdict be said about original WAUT ?
- prove that session automaton models fragment of the behavior of the WAUT
- Inverse preservation (violation) of
  - Safety properties
  - Properties whose counter examples are infinite
- Reachability checked on a single path (Limitation of LTL)
  - Ex: *user can reach a page with e-shop return policy*
  - Negate property: *on all paths e-shop return policy always absent* $\Rightarrow$ safety property
  - If negation is invalid then original property is valid

Prototype Tool



- Analysis of execution traces and model generation
- Automata model visualization and statistical data
  - Visual
  - Textual

- Property based attribute selection
- Execution interception and monitoring



Evaluation – Tool Performance

URL	Automata Model	Time
www.crim.ca	1 automaton, 294 states, 3879 transitions	2 min, 32 sec.
www.umontreal.ca	1 automaton, 267 states, 1657 transitions	4 min, 51 sec.
www.computer.org	2 automata, 36 global states, 213 transitions	1 min.
www.concordia.ca	4 automata, 2049 global states, 28204 transitions	1 min.
www.eclipse.org	9 automata, 847 global states, 9652 transitions	1 min, 20 sec.
www.berkeley.edu	14 automata, 19802 global states, 72801 transitions	2 min.

- Automatic browsing using crawler
- Time to produce the models is relative to the following parameters:
  - server response time
  - content of web pages visited
  - number of attributes evaluated in web pages

Evaluation - Property Verification

- Non-Functional
  - *Number of links in each display (single or multi) should not exceed a certain threshold (depends on size of application).*
  - *Number of links in each display (single or multi) is balanced.*
  - *Combinations of certain words/objects are absent.*
- Functional
  - *Home page is reachable from every other page without going through a certain page X*.
  - *Secure pages are not reachable without authentication process*.
  - *Privacy policy page is reachable from every page*.

	Property										
	1.1	**1.2**	**1.3**	**1.4**	**1.5**	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	**2.6**
Single window WA	2	2	1	2	0	0	3	0	1	1	0
Multi-display WA	1	5	5	5	3	0	4	1	n/a	n/a	n/a

Conclusion and Future Work

- Conclusions
  - Formal framework for run-time verification of WA
  - Extension of Linear Temporal Logic with scopes
  - System of web property patterns

- Future Work
  - Reconstruction of counter examples and play back
  - Partial automation of form population
  - Dynamic means using XPath to specify attributes
  - Extend LTL with temporal scopes
  - Implementation of specification patterns
  - Address emerging technologies
    - Ajax (Asynchronous Java + XML)
    - Web services composition

Questions?