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AIST/JAIST joint workshop on verification technology

A Toolkit for Generating and Displaying Proof Scores in the OTS/CafeOBJ Method

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Background

Formal Methods

- effective for systems are built safely and reliably.

The OTS/CafeOBJ method[Ogata 2003-]

- can model distributed systems as transition systems called OTS (Observational Transition Systems)
- can describe the system in CafeOBJ which is an algebraic specification language
- can verify that the system has invariant properties by induction on number of transition rules applied.
- easy to learn for ordinary engineers
    - based on (one-way) equational reasoning

Problem

Verification in the OTS/CafeOBJ method

Hundreds or thousands lines code

Base case

proof passage

Inductive step for $Transition_1$

Case splitting with pred. p_1

Case: p_1 holds

proof passage

Case: p_1 doesn't hold

proof passage

Inductive step for $Transition_n$

1. We must write proof score maintaining case splitting
2. We must check each reduced result is the expected term (= true)

☞ human errors may occur.

☞ disturb humans from concentrating on intellectual work.

```
open ISTEP
  op d1 : -> D1 .
  op d2 : -> D2 .
  ...
  eq p1 = true .
  ...
  eq s' = Transition1(s,...) .
  red SIH implies istep(...) .
close
```

Our solution

Generating and checking proof scores

We must specify to generate proof scores:

1. predicate to be proven
2. list of predicates to be used in case splitting
3. list of lemmas to be strengthen induction hypothesis

```
mod PROOF-SCRIPT {
  op d1 : -> D1 .
  op d2 : -> D2 .
  ...
  eq basecase = inv(...) .
  eq inductive = istep(...) .
  trans predicates(Transition1(S)) = p1 .
  ...
  trans lemmas(Transition1(S)) = inv1 .
  ...
}
```

Generated, Checked
Display hierarchically

Base case

proof passage

Inductive step for $Transition_1$

Case splitting with pred. p_1

Case: p_1 holds

proof passage

Case: p_1 doesn't hold

proof passage

Inductive step for $Transition_n$

CASE tool platform

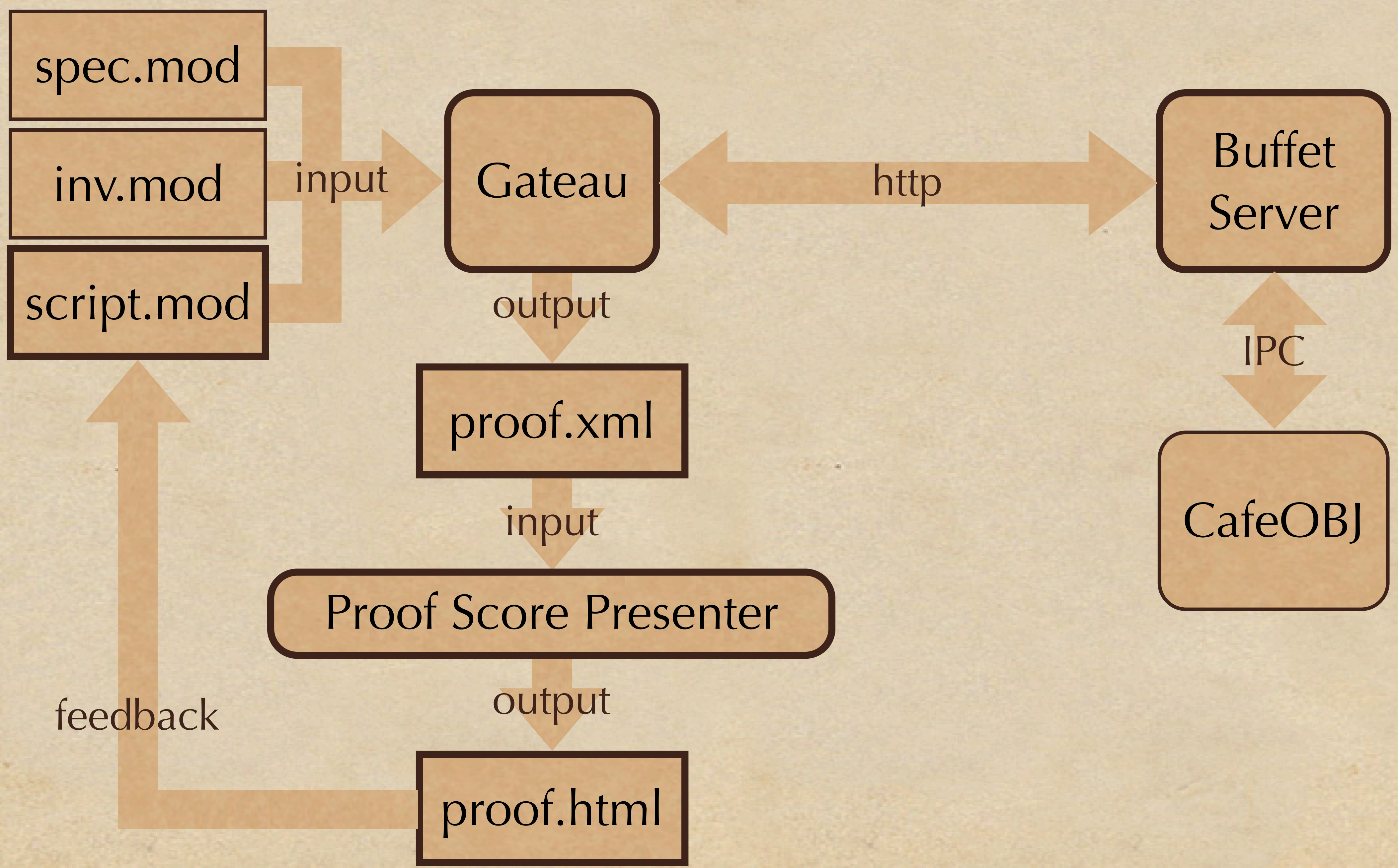
We propose a CASE tool platform CafeOBJ/XML

- based on XML technology
- has a syntax corresponding to abstract syntax of CafeOBJ
- also represents proofs

Design policy of CafeOBJ/XML

- scope: describing specifications and proofs.
- makes implementing CASE tools easier.
- doesn't depend a specific programming language.

Overview of Buffet toolkit



Ex. A Mutual Exclusion

We verify that

```
    var lock := false
l1: Remainder Section
l2: repeat until ¬(fetch&store(lock, true))
    Critical Section
cs: lock := false
```

has the mutual exclusion property.

Modeling with OTS

Data types:

- B = { true, false } .... Boolean values
- P = { p_1, p_2, ... } .... Set of process IDs
- L = { l1, l2, cs } .... Set of location labels

Note that equivalence relation denoted by '=' for each data type have been defined.

Modeling with OTS

Universal state space: Υ

set of **Observers** = $\{ o : \Upsilon \rightarrow D \}$

- $lock : \Upsilon \rightarrow B$
- $loc_p : \Upsilon \rightarrow L$ for $p \in P$

set of **Initial states**

- $\{ s_0 \mid lock(s_0) = \text{false} \wedge \forall p \in P. loc_p(s_0) = \text{l1} \}$

set of **Transitions** = $\{ t : \Upsilon \rightarrow \Upsilon \}$

- $try_p : \Upsilon \rightarrow \Upsilon$ for $p \in P$
- $enter_p : \Upsilon \rightarrow \Upsilon$ for $p \in P$
- $leave_p : \Upsilon \rightarrow \Upsilon$ for $p \in P$

Modeling with OTS

var *lock* := false

l1: Remainder Section

l2: **repeat until**

¬(fetch&store(*lock*, true))

Critical Section

cs: *lock* := false

Definition of try_p **:**

$c_{tryp}\ (s) \equiv loc_p(s) = \text{l1}$

$try_p(s')$ where $c_{tryp}\ (s)$ holds

$lock(s') = lock(s)$
$loc_p(s') = \text{l2}$
$loc_q(s') = loc_p(s) \quad \text{if p} \neq \text{q}$

where $c_{tryp}\ (s)$ doesn't holds
nothing changes

Invariants

Execution sequence {s_0, s_1, ... } satisfies:

- s_0 is in the set of initial states
- there exists a transition for each pair of (s_i, s_{i+1})

Reachability

- State s is ***reachable***: there exists an execution sequence of an OTS in which s appears.

Invariants

- A predicate p such that $p(s)$ holds for every reachable state s.
- In the ex., $\forall i,j \in P. loc(s,i) = \mathrm{cs} \wedge \mathrm{loc}(s,j) = \mathrm{cs} \Rightarrow i = j$

Describing invariant

Invariant candidates are described:

```
mod INV { pr(OTS-SPEC)
  op inv1  : ϒ … -> Bool
  op inv2  : ϒ … -> Bool
  …
  eq inv1(S:ϒ,…) = … .
  eq inv2(S:ϒ,…) = … .
  …
}

mod ISTEP { pr(INV)
  ops s s' : -> ϒ
  op istep1  : … -> Bool
  op istep2  : … -> Bool
  …
  eq istep1(…) = inv1(s,…) implies inv1(s',…) .
  eq istep2(…) = inv2(s,…) implies inv2(s',…) .
}
```

Signatures of invariants

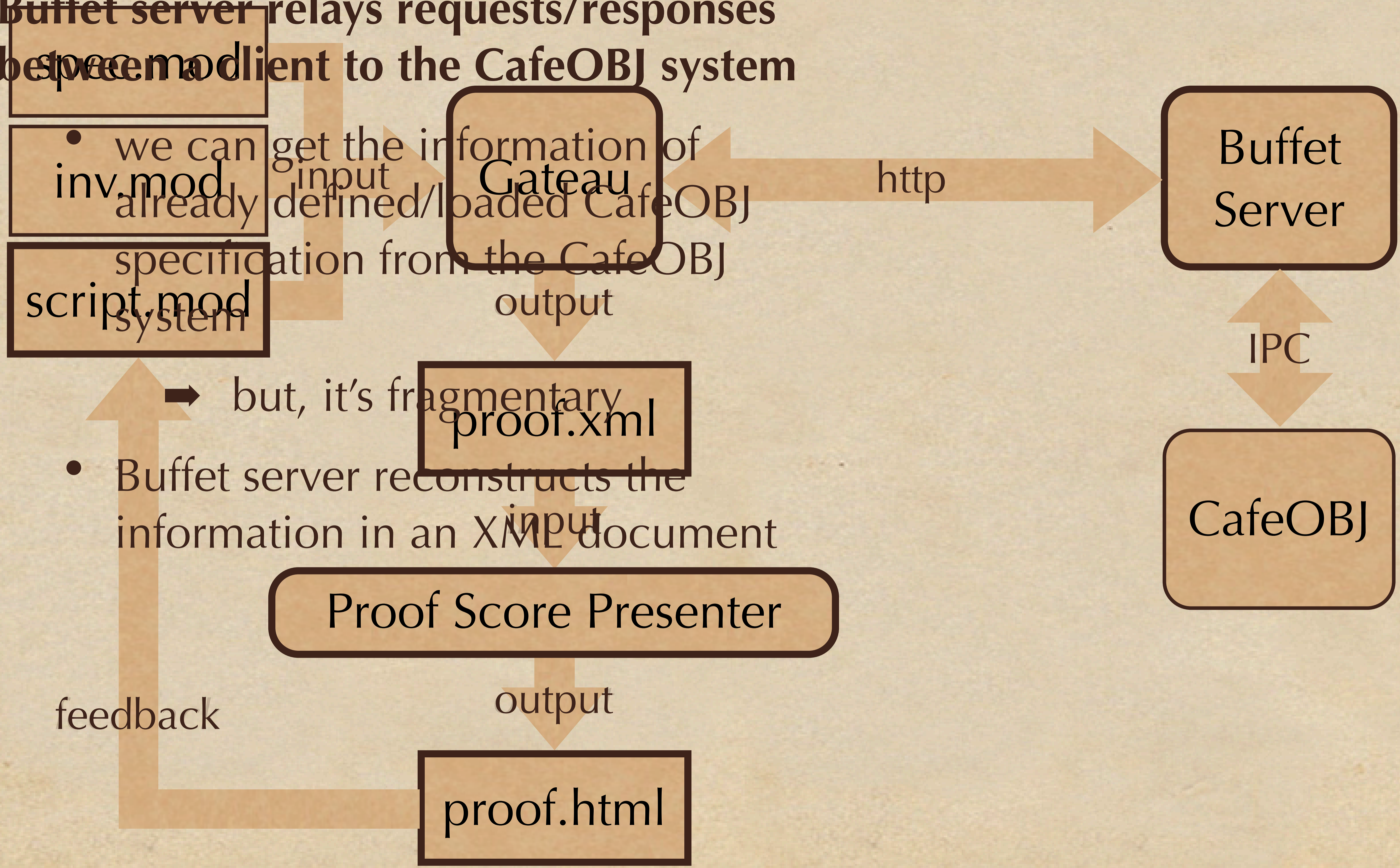
Invariants denoted by CafeOBJ term

Terms denoting reasonings in the inductive step

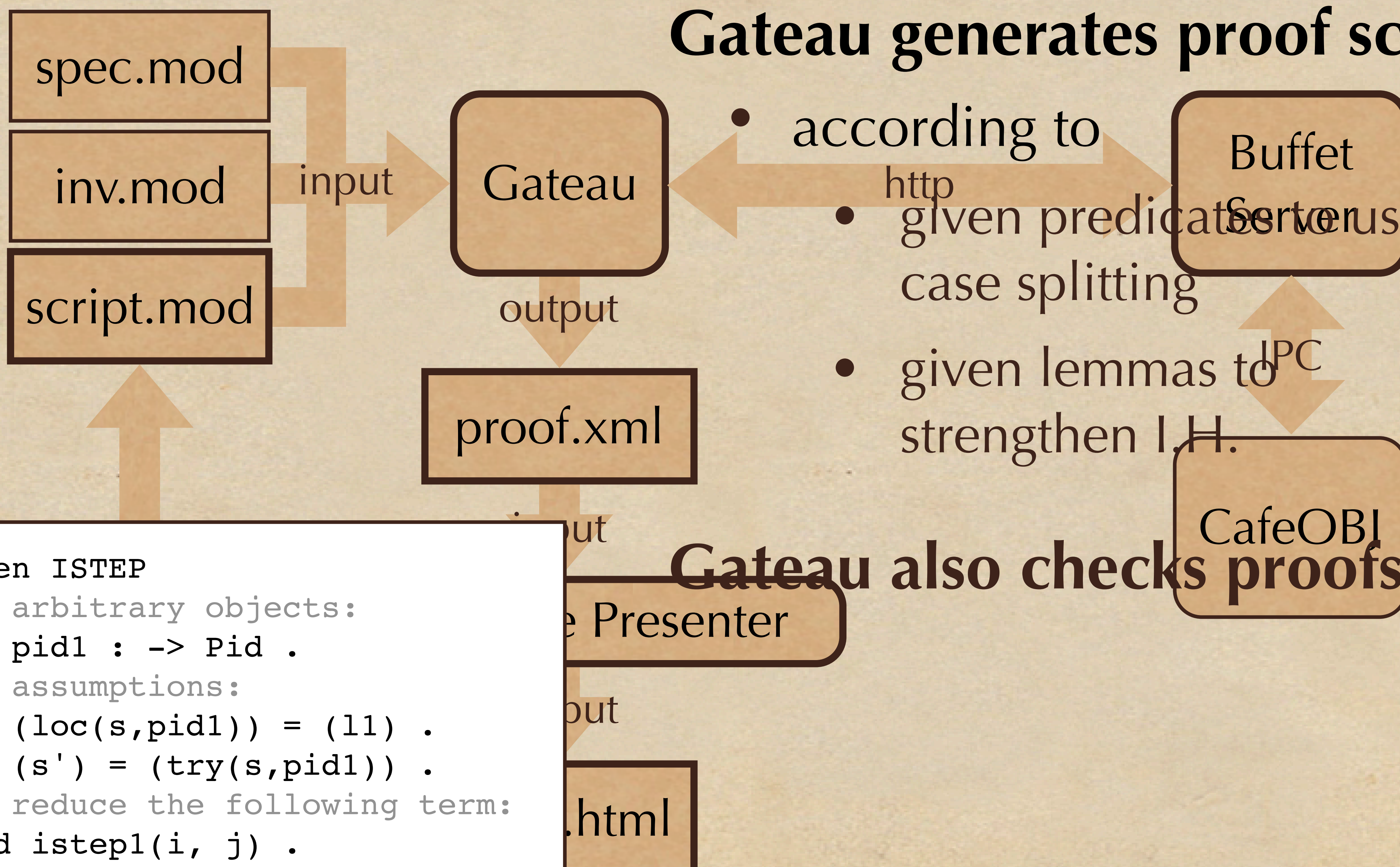
Buffet server

Buffet server relays requests/responses between a client to the CafeOBJ system

- we can get the information of already defined/loaded CafeOBJ specification from the CafeOBJ system
  - ➡ but, it's fragmentary
- Buffet server reconstructs the information in an XML document



Gateau



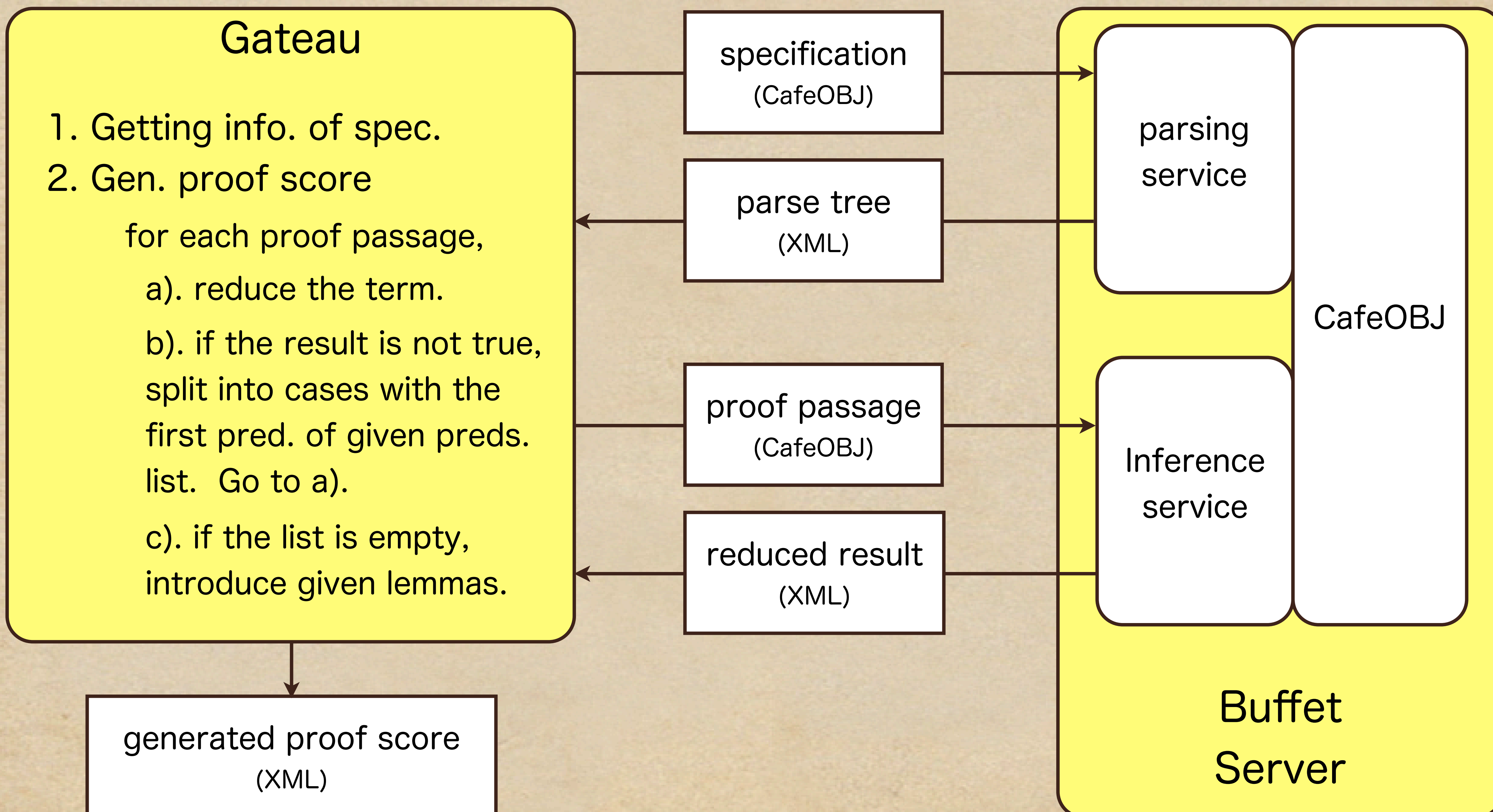
Gateau generates proof scores

- according to
  - given predicates to use for case splitting
  - given lemmas to strengthen I.H.

Gateau also checks proofs

```
open ISTEP
-- arbitrary objects:
op pid1 : -> Pid .
-- assumptions:
eq (loc(s,pid1)) = (l1) .
eq (s') = (try(s,pid1)) .
-- reduce the following term:
red istep1(i, j) .
close
```

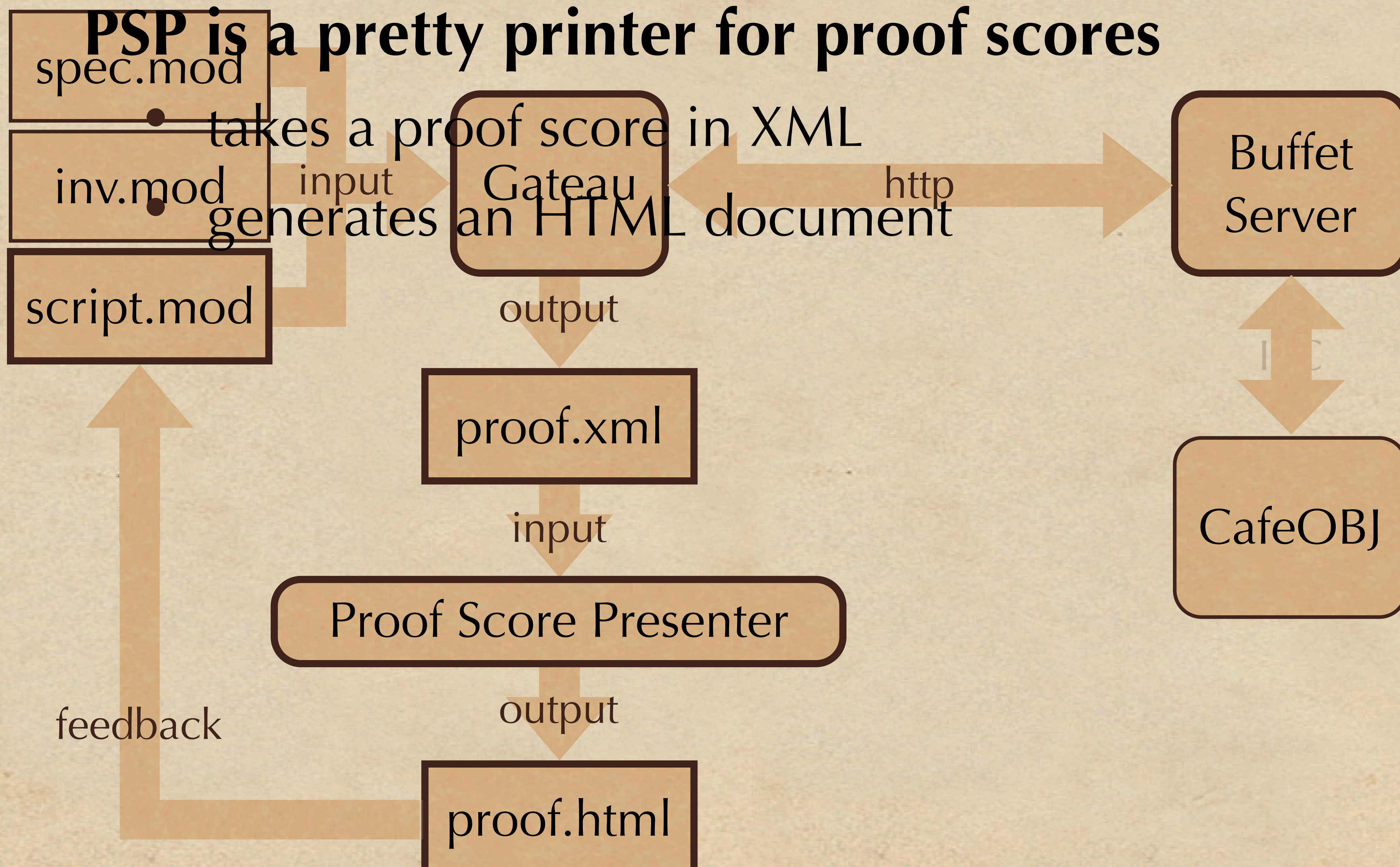
How to gen. proof score



Proof Score Presenter

PSP is a pretty printer for proof scores

- takes a proof score in XML
- generates an HTML document



There are 7 cases, 3 cases need human's help.

▶ base

Hierarchical view
with disclosing triangles

▼ action: try

case splitting: c-try(s, pid1)

▼ case: true

Displaying the part of proof scores
for which further case analysis
should be done and/or
lemmas should be used

```
open ISTEP
-- arbitrary objects:
op pid1 : -> Pid .
-- assumptions:
eq (loc(s,pid1)) = (l1) .
eq (s') = (try(s,pid1)) .
-- reduce the following term:
red istep1(i, j) .
close
```

result:

```
    ((((if (pid1 = i) then l2 else loc(s,i) fi) = cs) and ((if (pid1 = j) then l2
    else loc(s,j) fi) = cs)) and ((loc(s,i) = cs) and (loc(s,j) = cs)))

xor ((((if (pid1 = i) then l2 else loc(s,i) fi) = cs) and ((if (pid1 = j) then l2
    else loc(s,j) fi) = cs)) and (((loc(s,i) = cs) and (loc(s,j) = cs)) and (i =
    j)))

xor (((if (pid1 = i) then l2 else loc(s,i) fi) = cs) and ((if (pid1 = j) then l2
    else loc(s,j) fi) = cs))

xor (((if (pid1 = i) then l2 else loc(s,i) fi) = cs) and (((if (pid1 = j) then l2
    else loc(s,j) fi) = cs) and (i = j)))

xor true
```

▶ case: false

A hidden part of proof scores

▼ action: enter

case splitting: c-enter(s, pid1)

▼ case: true

Other case studies

Otway-Rees authentication protocol

- 1 secrecy property (48 cases)
- 3 lemmas (36-37 cases)

NSLPK authentication protocol

- 1 secrecy property (37 cases)
- 6 lemmas (24-65 cases)

Conclusion

We have implemented the Buffet toolkit

- can generate & check proof scores automatically
  - generated proof scores cover all cases
  - success of proofs depends on given predicates and lemmas
- can display proof scores hierarchically
  - provided views helps the verification
- can be applied including non-trivial problems
  - Simple mutual exclusion
  - NSLPK, and Otway-Rees authentication protocols

Implemented tools

Buffet Server (1,200 lines, in Perl)

Gateau (800 lines, in Perl)

Proof Score Presenter (600 lines, in XSLT)

Eclipse plug-ins (working)

- CafeOBJ Editor (300 lines, in Java)
- Proof Score Viewer (400 lines, in Java)
  - the final goal will be an Interactive Editor for Proof Score

Cafe2Maude (by Kong-san, in Java)

Future plan

Integrating Eclipse

- GUI based implementation (Gateau & PSP)
  - more interactive

More tightly integrating Eclipse

- Test Driven Development
  - Test case generation from proof scores

Demonstration