Specifying and Testing Properties for Distributed Components: *Liveness and Locality*

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Conclusions

- Locality is important
  - global properties are hard to gather (and test)
- Specifying and testing safety is *not* enough
  - complete specifications include liveness properties too
- It *is* possible to test liveness in a limited sense
  - even though the testing is limited, still useful
- Prototype: application to CORBA

performance

formal methods & specification

validation

Observation #1: Importance of Locality

- Often, properties of interest are global.
  - invariant: # tokens in system = 1
- Testing such properties requires gathering global state.
  - for stable properties, can calculate a snapshot
  - expensive communication overhead
- Alternative: collections of local properties only.
  - no component creates (or destroys) tokens
  - can be easily tested (locally) for each component
- This simple observation has some ramifications…

Requires-Ensures Specifications

- Sequential specifications are often based on pre/post conditions.

IDL

```
interface Stack {
  void push (long v);
  long pop ( );
};
```

IDL++

```
interface Stack {
  state:  sequence<int> Q;
  state:  int MaxSize = 100;
  void push (long v);
     requires:   |Q| < MaxSize
     modifies:   Q
     ensures:    Q = ‘Q ++ v
  long pop ( );
     …etc...
};
```

Problem: Precondition Paradox

- In sequential systems, the requires clause is the *client's* responsibility.

Client.cpp

```
Stack s;
…
if (!s.full())  {
   //assert: Stack s is not full
   s.push(3)
}
```

Problem: Precondition Paradox

- In distributed systems, there may be more than one client!

Client1.cpp

```
if (!s.full())  {
   //can Stack s be full?
   s.push(3)
}
```

Stack s

Client2.cpp

- "Requires" is a property of entire system!

Implication: Trivial “Requires” Clauses

- So, a more appropriate way to specify push:

```
void push (long v);
      requires:   true
      modifies:   Q
      ensures:    |`Q| < MaxSize   ==>   Q = `Q ++ v
```

- If non-trivial “requires” clause is used:
  - is often a system property
  - expensive (potentially impossible) for client to check

Observation #2: The Need for Liveness

- It is tempting to think of servers as objects and messages as method invocations.
  - encouraged by popular middleware implementations
- Then use familiar specs from sequential objects.
- These specs do not address *liveness*.
  - “something eventually happens”
- Liveness really is needed for peer-to-peer systems.
  - a component that guarantees a reply (e.g. bidders)
  - a component that accepts messages while working (e.g. a distributed branch & bound tree search)

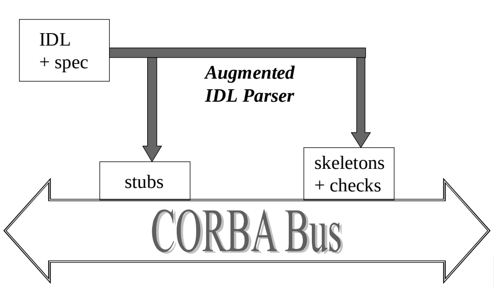
Transience

- Fundamental operator: transient
- transient.P means:
  - if P is ever true, eventually it becomes false
    - transient.(#tokens_received > #tokens_sent)
  - and, this transition is guaranteed by a single action
    - each process responsible for returning its tokens
- Enjoys a nice compositional property:
  - transient.P.C   ==>   transient.P.(C||S)
  - unlike leads-to, transient properties preserved under composition

Observation #3: Testing Transience

- Like any progress property, can never detect its violation
  - how long to we wait before giving up?
- Since we it cannot be tested, don’t.
- But what do programmers do in practice?
  - observe possible progress bug
  - abort program and insert print statements!
  - so programmers do have some intuition about how “quickly” to expect progress
- Programmers would benefit from tool support.

Our Extensions to CORBA IDL



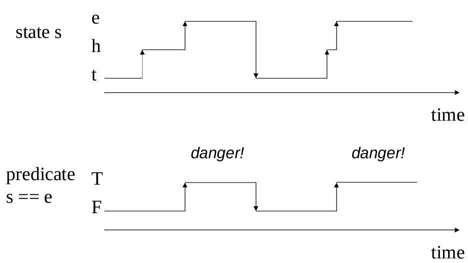
Example: Dining Philosopher

- Philosophers do not “eat” forever.

```
interface Philosopher  {
    state: enum{t,h,e} s;
    transient: (s == e)
    void grant_fork();
}
```

```
void Philosopher::grant_fork()  {
    //generated testing code
    //user-supplied code
    //generated testing code
}
```

Example: Philosopher



Transient History

- For each transient predicate, keep a history.
  - whether predicate is true or false
  - when it last became true
- Update history after each method.
- History class is standard.
  - function pointer for the predicate to test
  - some predicates can be generated
  - evaluation of abstract state must be written

Transient History Class

```
template <class AbstractState>
struct TransientHistory {
    boolean holds;
    long time_stamp;
    boolean (*predicate)(const AbstractState&);

    void initialize (const AbstractState& state) {
        holds = (*predicate)(state);
        if (holds)
            time_stamp = get_current_time();
    }

    void update (const AbstractState& state) {
        boolean b = (*predicate)(state);
        if (!holds && b)
            time_stamp = get_current_time();
        holds = b;
    }
};
```

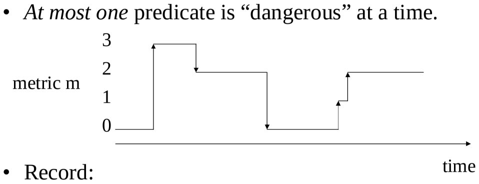
Quantification and Transience

- Many transient properties are quantified.
  - e.g. ⟨ ∀k :: transient.(metric = k) ⟩
- This corresponds to an infinite number of histories (one for each k)!

  transient.(metric = 0) ∧ transient.(metric = 1) ∧ …
- Keeping all these histories is not practical.
- In many cases, there is an alternative…

Functional Transience

- Abstract state determines value of the dummy (k).
- *At most one* predicate is “dangerous” at a time.



- Record:
  - whether predicate is true or false
  - value of k needed to make it true
  - time of last transition

Functional Transience History

```
struct FunctionalTransientHistory {
    boolean holds;
    long time_stamp;
    int free_var;
    int (*dummy)(const AbstractState&);
    boolean (*predicate)(const AbstractState&, int);

    void initialize (const AbstractState& state) {
        free_var = (*dummy) (state);
        holds = (*predicate) (state, free_var);
        if (holds)
            time_stamp = get_current_time();
    }

    void update (const AbstractState& state) {
        int v = (*dummy) (state);
        int b = (*predicate) (state, v);
        if ((!holds && b) || ((v != free_var) && b))
            time_stamp = get_current_time();
        holds = b;
        free_vars = v;
    }
};
```

Augmented IDL Parser

- User provides annotations in IDL
  - given as pragmas
- Automatically generated in skeleton code:
  - classes for abstract state and predicate histories
  - functions that calculate these predicates
  - functions to calculate functional transient dummies
  - calls to initialize and update these histories
  - function headers for required abstraction function
- Tester provides in skeleton code:
  - body of the abstraction function

Introduction

• Locality is important – global properties are hard to gather (and test)	performance
• Specifying and testing safety is *not* enough – complete specifications include progress properties too	formal methods & specification
• It *is* possible to test progress in a limited sense – even though the testing is limited, still useful	validation
• Work in progress: application to CORBA	

Future Work

- Experimentation and evaluation of prototype
  - extensive use in Jan-Mar 2000 (25 grad students)
- Extension to safety properties
- Other middleware technologies: e.g., Java RMI
  - XML-based language for certificate specifications
  - leverage OCL
- Client-side use of certificate specifications
  - proof-carrying code

Transient History Class

```
struct TransientHistory {
  boolean holds;
  long time_stamp;
  boolean (*predicate)(const AbstractState&);
  void initialize (const AbstractState& state) {
    holds = (*predicate)(state);
    if (holds)
      time_stamp = get_current_time();
  }
  void update (const AbstractState& state) {
    boolean b = (*predicate)(state);
    if (!holds && b)
      time_stamp = get_current_time();
    holds = b;
  }
};
```