Encapsulating Concurrency as an Approach to Unification

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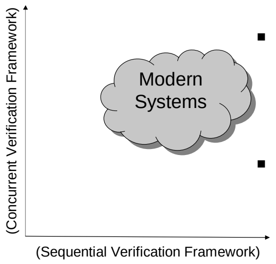
Modular Verification

- Prove the correctness of an implementation of a component using only the specification of its environment.

Framework Choice

- Sequential Framework
  - Assume a single thread of execution
  - Collection of passive objects makes up the environment
  - Think of the environment behavior in terms of Hoare-style pre- and post-conditions, weakest pre-conditions, etc.
- Concurrent Framework
  - Explicitly acknowledge the existence of multiple, concurrently executing threads
  - Collection of active objects makes up the environment
  - Think of the environment behavior in terms of Rely Guarantees, Hypothesis Conclusion, TLA, IOAutomata, etc.

The Unification Problem

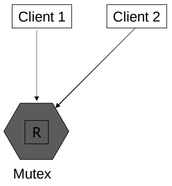

(Concurrent Verification Framework)
Modern Systems
(Sequential Verification Framework)

- Major issues in sequential verification
  - Contract style to use
  - Impact of pointers, references, aliasing, etc.
  - How to reason about inheritance?
- Major issues in concurrent verification
  - Deadlock detection and avoidance
  - Choice of synchronization primitives
  - Scheduling of processes
  - Protocol verification

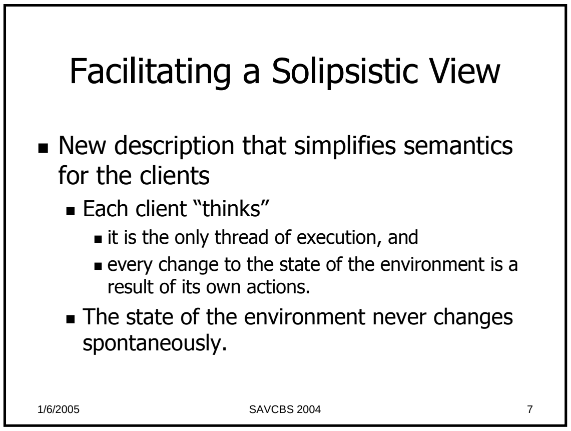
Our Approach

- Extend a sequential verification framework (RESOLVE) to the domain of concurrent systems

Example: Mutual Exclusion

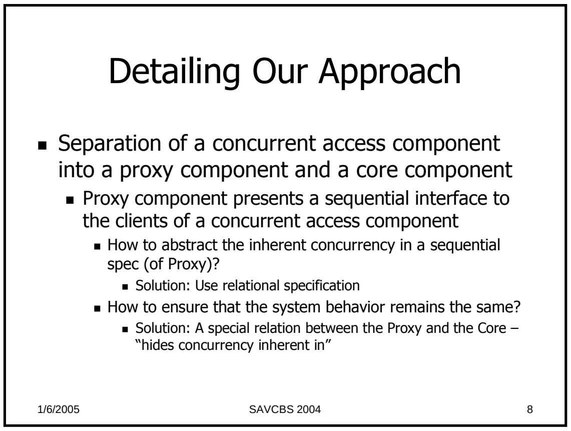


- Several clients wanting mutually exclusive access to a resource
- The environment for clients is no longer passive
  - Clients are aware of the existence of other concurrently executing clients in the system
  - Clients negotiate with each other on mutually exclusive access to the resource.
- Clients can't use Sequential Verification Framework



Facilitating a Solipsistic View

- New description that simplifies semantics for the clients
  - Each client "thinks"
    - it is the only thread of execution, and
    - every change to the state of the environment is a result of its own actions.
  - The state of the environment never changes spontaneously.



Detailing Our Approach

- Separation of a concurrent access component into a proxy component and a core component
  - Proxy component presents a sequential interface to the clients of a concurrent access component
    - How to abstract the inherent concurrency in a sequential spec (of Proxy)?
      - Solution: Use relational specification
    - How to ensure that the system behavior remains the same?
      - Solution: A special relation between the Proxy and the Core – "hides concurrency inherent in"

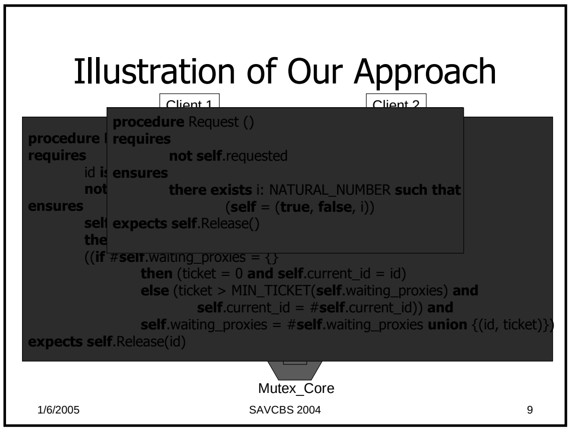
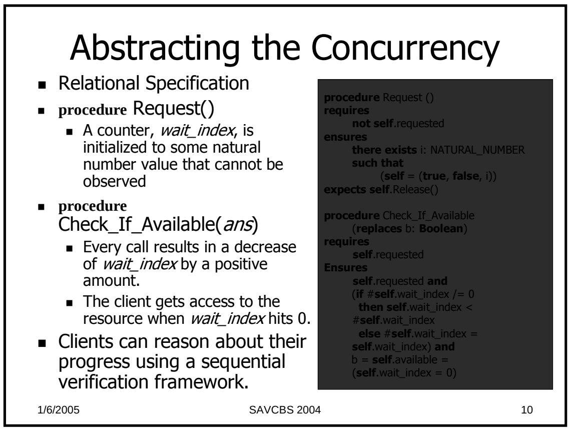


Illustration of Our Approach

```
procedure Request ()
requires
        not self.requested
ensures
        there exists i: NATURAL_NUMBER such that
                (self = (true, false, i))
expects self.Release()
```

```
procedure F
requires
        id i
        not
ensures
        self
        the
        ((if #self.waiting_proxies = {}
                then (ticket = 0 and self.current_id = id)
                else (ticket > MIN_TICKET(self.waiting_proxies) and
                        self.current_id = #self.current_id)) and
                self.waiting_proxies = #self.waiting_proxies union {(id, ticket)})
expects self.Release(id)
```

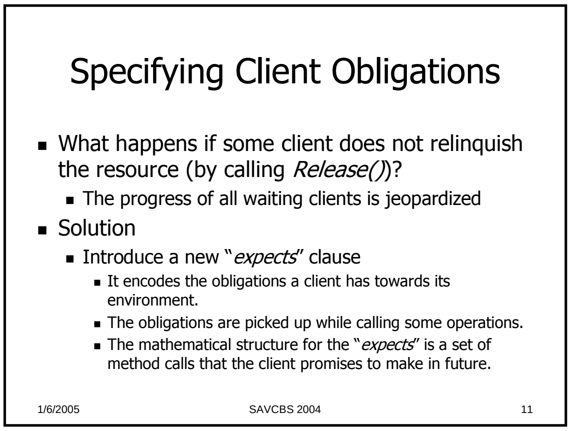


Abstracting the Concurrency

- Relational Specification
- **procedure** Request()
  - A counter, *wait_index*, is initialized to some natural number value that cannot be observed
- **procedure** Check_If_Available(*ans*)
  - Every call results in a decrease of *wait_index* by a positive amount.
  - The client gets access to the resource when *wait_index* hits 0.
- Clients can reason about their progress using a sequential verification framework.

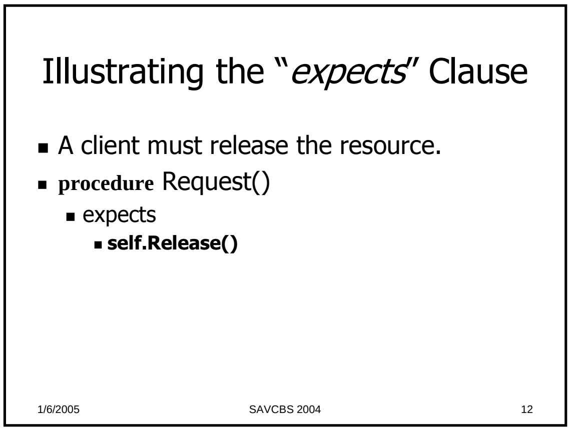
```
procedure Request ()
requires
      not self.requested
ensures
      there exists i: NATURAL_NUMBER
      such that
            (self = (true, false, i))
expects self.Release()

procedure Check_If_Available
      (replaces b: Boolean)
requires
      self.requested
Ensures
      self.requested and
      (if #self.wait_index /= 0
        then self.wait_index <
      #self.wait_index
        else #self.wait_index =
      self.wait_index) and
      b = self.available =
      (self.wait_index = 0)
```



Specifying Client Obligations

- What happens if some client does not relinquish the resource (by calling *Release()*)?
  - The progress of all waiting clients is jeopardized
- Solution
  - Introduce a new "*expects*" clause
    - It encodes the obligations a client has towards its environment.
    - The obligations are picked up while calling some operations.
    - The mathematical structure for the "*expects*" is a set of method calls that the client promises to make in future.



Illustrating the "*expects*" Clause

- A client must release the resource.
- **procedure** Request()
  - expects
    - **self.Release()**

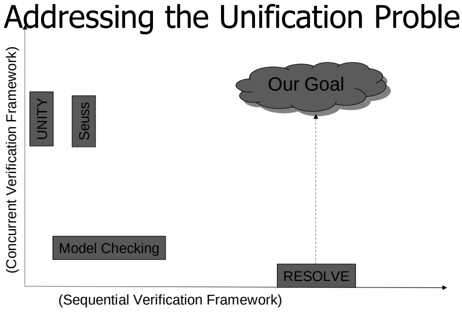
Summarizing the Contributions

- Goal : To present a sequential interface to the clients of a concurrent-access component
  - Extract a sequential “proxy” specification from a concurrent-access component
  - Use relational specifications to abstract the effects of concurrency
  - Introduce “*expects”* clause to formalize the client obligations

Benefits of Our Approach

- The effects of concurrency do not bleed through to the client
  - Client verification can be carried out using a sequential verification framework
  - Many client components are possible, all of whom benefit from this approach
- The effects of concurrency are limited to just one component, the proxy component
- Moreover, because of the “hides concurrency inherent in” relation between the proxy and the core, the proof of proxy implementation is not too complicated either
  - Illustrated by the proof for Mutex_Proxy implementation in the paper

Addressing the Unification Problem


(Concurrent Verification Framework)
UNITY
Seuss
Our Goal
Model Checking
RESOLVE
(Sequential Verification Framework)

Open Issues

- The “*expects”* clause
  - Its mathematical structure – multi-set, string, or some other model instead of a set?
  - Proof obligations for a non-terminating client
- Application of our approach to *cooperative* concurrent systems
- Proof system for verifying the correctness of core component implementations

More Questions and Comments?