CCC Seminar

Composable, Nestable, Pessimistic Atomic Statements

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Introduction

- Few extensions to the C programming language → “shelters”
- Compiler pass transforms “shelter code” to C code with calls to shelter runtime
- Shelter runtime ensures atomicity (and other properties) given correct calls to the runtime
Shelter code elements

- Shelter type: shelter_t
- Type annotation: sheltered_by( ... )
- Atomic block: atomic { ... }
- Function annotation: needs_shelters( ... )

→ “relatively” small annotation overhead
shelter_t type

Normal C type, no special restrictions

shelter_t shelter_variable;
struct some_struct {
    shelter_t shelter_field;
    int other_struct_field;
};
shelter_t some_function(shelter_t param);
sheltered_by type annotation

Annotation for shared objects

shelter_t shelter_variable;
int sheltered_by(shelter_variable) some_int;
struct some_struct {
    shelter_t shelter_field;
    int sheltered_by(shelter_field) other_struct_field;
};
atomic {
    /*
    guarantees atomic access to sheltered objects
    needs correct annotations
    open_atomic { … } & force_open_atomic { … } for open nesting
    */
}
needs_shelters function annotation

- Required to avoid whole-program analysis
- Somewhat complicated
- Not important for understanding of the idea
- See Appendix
Example (from paper)

typedef struct {
    int sheltered_by(s) id;
    float sheltered_by(s) balance;
    shelter_t s;
} account_t;
Example (from paper)

```
needs_shelters(a->s)
void deposit(account_t* a, float d) {
    a->balance += d; // not atomic, see next slide
}

needs_shelters(a->s)
void withdraw(account_t* a, float d) {
    a->balance -= d; // not atomic, see next slide
}
```
Example (from paper)

void transfer(account_t* to, account_t* from, float amount) {
    atomic {
        // here accesses become atomic
        withdraw(from, amount);
        deposit(to, amount);
    }
}
Implementation

- No whole-program analysis required
- Supports explicit external locks
  - Through shadow shelters (→ more annotations)
- Supports condition variables (→ more annotations)
- Supports both open- and closed-nesting
  - Closed-nesting: Changes become visible at the end of outer-most atomic block
  - Open-nesting: Changes become visible at the end of each nested atomic block resp.
Implementation

- Timestamp based (similar to database transactions)
  - Global counter → contention → exponential back-off
- Pessimistic: First makes sure it's safe to execute atomic blocks, then executes them
- Not Optimistic: Execute code and if a problem is detected roll-back changes (roll-back may be expensive or impossible e.g. for IO)
- Must know used shelters before atomic block
  - For struct fields program analysis may be imprecise (see appendix)
    - Each struct with shelters has its own global shelter which can be used for this case → quite extreme (problematic for the sqlite benchmark)
    - Could use more fine-grained shelter hierarchy → might require whole-program analysis
Formalism

- Paper introduces formalism for shelter semantics
- Operational semantics
- Rather complicated (see appendix & paper)
- Allows to formally establish useful properties about shelters
  - Deadlock freedom
  - Partial atomicity for sheltered objects
  - No guarantees about starvation or fairness
Benchmarks

• Benchmarked with 13 different programs
  • Including
    – SQLite database system
    – parallel bzip2 (pbzip2)
    – n-body simulation (ebarnes)
    – oatomic (using open nesting)
  • Executed on 2.27GHz Intel Xeon X7560 with four processors each with eight cores (total 32 cores) with 32GB memory without Hyperthreading
Benchmark

- Compared against
  - explicit locking (reference)
  - Autolocker
  - Intel C/C++ compiler software transactional memory
  - Single global lock
  - Shelters implemented using RWLocks
Benchmark

Figure 5. Average percent slowdown with respect to explicit locking over all benchmarks versus the number of threads. Lower is better.
Questions?
Appendix
needs_shelters function annotation

- Required if the function is called inside an atomic block
- Must declare which shelters are used inside function
- For calls to other functions, must also declare their used shelters
- Can use globals & parameter expressions
- Compiler & runtime give errors if they are missing
- Missing annotations can lead to data-races, but not deadlocks
needs_shelters function annotation

needs_shelters(shelter_variable)
void some_function() { ... }

needs_shelters(arg->shelter_field)
void another_function(struct some_struct arg)
{ ... }

• needs_shelters is a var arg function
Example (from Paper)

void idTransfer(int toId, int fromId, float a) {
    // this example will require the global account_t shelter
    atomic {
        account_t *to = accountLookup(toId);
        account_t *from = accountLookup(fromId);
        withdraw(from, a);
        deposit(to, a);
    }
}
Example (from Paper)

open_atomic {
    for (t = l->head; t; t = t->next) {
        atomic {
            withdraw(t->from, a);
            deposit(t->to, a);
        }
    }
}
Formalism: Definitions

Declaration \( d ::= \) int \( v \) sheltered by \( x \)

Trace \( T ::= (t_1, s_1), \ldots, (t_m, s_m) \)

Statement \( s ::= \) reserve(\( \sigma_1, \ldots, \sigma_m \))

\[ \mid \text{register}(\sigma_1, \ldots, \sigma_m) \]
\[ \mid \text{pop} \]
\[ \mid v ::= v_1 + v_2 + n \]

Shelter (\( \Sigma \)) \( \sigma ::= v_\sigma \mid x \)

Identifiers \( v, x \) \hspace{0.5cm} \text{Integers} \hspace{0.5cm} t, n, m

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Figure 2. Traces of shelter-based programs.
Formalism: Rules

\[ \text{regfor}(H, t, v) \quad \text{regfor}(H, t, v_1) \quad \text{regfor}(H, t, v_2) \]

\[ R, H \models (t, v := v_1 + v_2 + n) \]

\[ H(t) = \emptyset \lor \text{subsumed}([\sigma_1, \ldots, \sigma_m], R(t)) \]

\[ R, H \models (t, \text{reserve}(\sigma_1, \ldots, \sigma_m)) \]

\[ \text{subsumed}([\sigma_1, \ldots, \sigma_m], R(t)) \quad m \geq 1 \]

\[ R, H \models (t, \text{register}(\sigma_1, \ldots, \sigma_m)) \]

\[ H(t) \neq \emptyset \]

\[ R, H \models (t, \text{pop}) \]

\[ R, H \not\models (t_1, s_1), \ldots, (t_m, s_m) \to \bot, \bot, \bot, \bot: \epsilon \]

\[ \text{access}(H, t, v) \quad \text{access}(H, t, v_1) \quad \text{access}(H, t, v_2) \]

\[ M, R, H, a : (t, v := v_1 + v_2 + n) \to M[v \to M(v_1) + M(v_2) + n], R, H, a \]

\[ R' = R[t \to \{\sigma_1, \ldots, \sigma_m\}] \]

\[ M, R, H, a : (t, \text{reserve}(\sigma_1, \ldots, \sigma_m)) \to M, R', H, a \]

\[ H' = H[t \to H(t) \cup \{(a, \sigma_1), \ldots, (a, \sigma_m)\}] \]

\[ \neg\text{cycle}(\text{impedes}(R, H')) \]

\[ M, R, H, a : (t, \text{register}(\sigma_1, \ldots, \sigma_m)) \to M, R, H', a + 1 \]

\[ b = \max \{a \mid (a, \sigma) \in H(t)\} \]

\[ H' = H[t \to [(a, \sigma) \mid (a, \sigma) \in H(t) \land a \neq b]] \]

\[ M, R, H, a : (t, \text{pop}) \to M, R, H', a \]

\[ R, H \models (t_1, s_1), \ldots, (t_m, s_m) \to \bot, \bot, \bot, \bot: \epsilon \]

\[ \text{subsumed}(\Sigma_1, \Sigma_2) = \forall \sigma_1 \in \Sigma_1. \exists \sigma_2 \in \Sigma_2. \sigma_1 \leq \sigma_2 \]

\[ \exists(a, \sigma) \in H(t_1), (a, \sigma) \in H(t_2). a_1 < a_2 \land \text{interferes}(\sigma_1, \sigma_2) \]

\[ \exists \sigma_2 \in R(t_2). \land \text{interferes}(\sigma_1, \sigma_2) \]

**Figure 3.** Trace Operational Semantics