Static Analysis of Reference-Counted Objects for the C Programming Language

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→ Static analysis to check reference counting

- ⚠ Rely on conventions or heuristics
- ⚠ Perform inter-procedural analysis
- ⚠ Limited support for language features

The Problem

Reference Counting

```
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- Counter is handled by the programmer
- Counter must equal the number of references
- Incorrect counters can cause memory leaks or use-after-free anomalies

Example

```
1  struct inode *inode_alloc(struct fs *fs) {
2      struct inode *i = ref_alloc(sizeof(*i));
3      if (i == NULL) return NULL;
4      i->i_fs = fs;
5      return i;
6  }
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Q3 How should `inode_alloc` behave?

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Q3 How should `inode_alloc` behave?

Q4 Is this code correct?

Our Approach

Overview

1. **Annotations**
2. **Static analysis**
   - 2.1 Simplification
   - 2.2 Annotation checking
   - 2.3 **State calculation**
   - 2.4 **State checking**

Annotations

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Which structures are reference-counted?

```
1 struct inode {
2     ...
3 } REF_TYPE;
```

```
1 struct fs {
2     ...
3 } REF_TYPE;
```

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Q2 How does `ref_alloc` behave?

Q3 How should `inode_alloc` behave?

How does `ref_alloc` behave?

```
1 extern void REF_TYPE *ref_alloc(size_t size)
2     REF_ACQUIRE_IF(__return__ != NULL, __return__);
```

Annotations

```
1 struct inode *inode_alloc(struct fs *fs) {
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How should `inode_alloc` behave?

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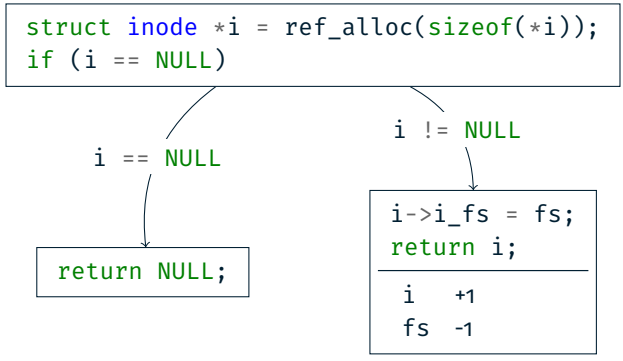
Static Analysis

```
foreach module-ast:
    m = simplify(module-ast)
    check_annotations(m)
    c = control_flow_graph(m)
→   s = calculate_state(c)
→   check_state(m, s)
```

Is this code correct?



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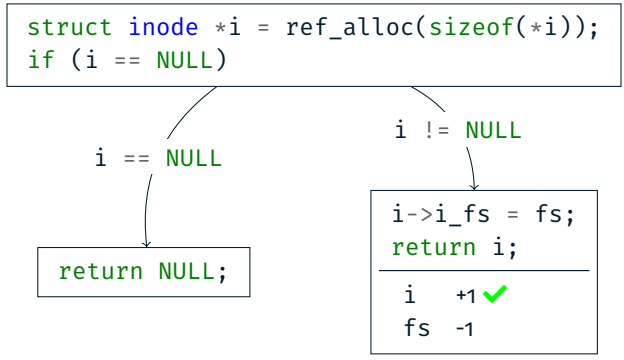

- Return value must have a reference delta of +1
  - `REF_ACQUIRE_IF(__return__ != NULL, __return__)`

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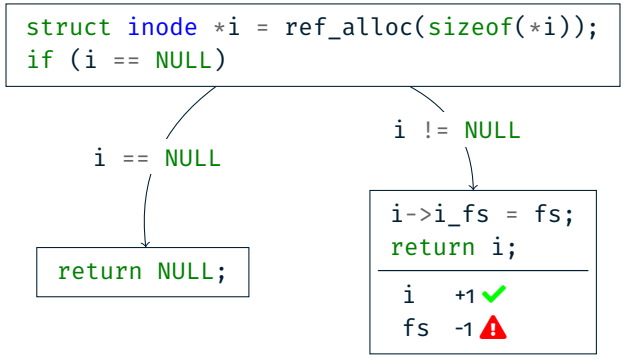

- Return value must have a reference delta of +1
  - `REF_ACQUIRE_IF(__return__ != NULL, __return__)`
- Any other value must have a reference delta of 0

Discussion

Evaluation

- Implemented in the FAUCCC static analyzer

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  - 33 / 605 structures ($\sim$ 5%)
  - 220 / 4433 functions ($\sim$ 5%)

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- Catches bugs before they are committed
  - Makes effectiveness evaluation difficult
- Number of annotations:
  - 33 / 605 structures ($\sim$ 5%)
  - 220 / 4433 functions ($\sim$ 5%)
- Very fast (<1 second) for most modules

Limitations

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- Conditional reference counting operations are rejected

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if (a == 2) ref_acquire(x);
/* ... */
if (b == 2) ref_release(x);
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- Aliased parameters can cause false negatives
- Reference cycles are not handled
- Conditional reference counting operations are rejected

```
if (a == 2) ref_acquire(x);
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→ These limitations are solvable

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- Add finalization analysis

Conclusion

- Static analyzer for reference-counting
- Annotations instead of conventions or heuristics
- Performs fast intra-procedural analysis

Q & A

For further questions:
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