

BLASTing Linux Code

— A Case Study on Software Model Checking —

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Motivation

- Operating systems are difficult to build and usually contain bugs; revealing, locating and correcting these bugs is costly
- Software Model Checking tools such as BLAST, MAGIC and SLAM are available, but relatively few case studies have been published
- Can BLAST aid a practitioner in order to find and avoid common programming errors?

1. BLAST Overview

- Generate instrumented program from C code by adding an `ERROR` label
- Compute abstraction; model check the abstraction in order to verify whether `ERROR` is reachable

([Henzinger et al., 2002](#))

- Has been applied to Windows and Linux device drivers ([Henzinger et al., 2002](#); [Beyer et al., 2005](#))

1.1 Using BLAST

- Use a temporal safety specification
- Use `assert()` statements
- Directly instrument the source code with `ERROR` labels

```
global int lockstatus = 0;
event
{
  pattern { lock($?); }
  guard   { lockstatus == 0 }
  action  { lockstatus = 1; }
}
event
{
  pattern { unlock($?); }
  guard   { lockstatus == 1 }
  action  { lockstatus = 0; }
}
```

1.1 Using BLAST

- Use a temporal safety specification
- Use `assert ()` statements
- Directly instrument the source code with `ERROR` labels

```
int lockstatus = 0;

void lock(void) {
    assert (lockstatus == 0);
    lockstatus = 1; return; }

void unlock(void) {
    assert (lockstatus == 1);
    lockstatus = 0; return; }
```

1.1 Using BLAST

- Use a temporal safety specification
- Use `assert()` statements
- Directly instrument the source code with `ERROR` labels

```
int lockstatus = 0;

void error (void) {
    ERROR: goto ERROR; }

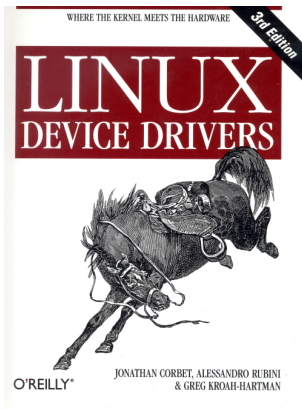
void lock(void) {
    if (lockstatus == 1)
        { error(); }
    lockstatus = 1; }

void unlock(void) {
    if (lockstatus == 0)
        { error(); }
    lockstatus = 0; }
```

2. Case Study

- Interesting properties:
 - memory safety
 - correct locking
- The cases:
 - known bugs from Linux 2.6.13 and 2.6.14
 - 8 examples for each group of properties

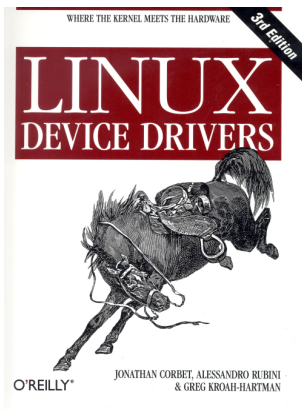
2.1 Memory Safety



"You should never pass anything to *kfree* that was not obtained from *kmalloc*." (Corbet et al., 2005)

- Several APIs for allocation and de-allocation
- General problems: Is a pointer valid at any time it is de-referenced?
Is it valid for a specific operation?

2.2 Correct Locking



"Neither semaphores nor spinlocks allow a lock holder to acquire the lock a second time; should you attempt to do so, things simply hang." ([Corbet et al., 2005](#))

- Are all locks initialised?
- Certain functions must not be called while a lock is held

2. Case Study

- Interesting properties:
 - memory safety
 - correct locking
- The cases:
 - known bugs from Linux 2.6.13 and 2.6.14
 - 8 examples for each group of properties

2.3 The Cases

Memory Safety	Example							
Error Type	1	2	3	4	5	6	7	8
NULL de-reference				x				
use-after-free	x	x	x		x			
double free								x
overrun error						x		
pointer arithmetic							x	
involves concurrency					x			

Locking Properties	Example							
Error Type	1	2	3	4	5	6	7	8
deadlock condition	x	x	x	x		x	x	
other API violation					x			x
involves concurrency					x			x

3. One Case in Detail

```
static int i2o_pci_probe()
{
    struct i2o_controller *c;
    ...
    c = i2o_iop_alloc();
    ...
    i2o_iop_free(c);
    ...
    put_device
    (c->device.parent);
    ...
    return rc;
}
```

1. Use a temporal safety specification
2. Manually add ERROR label; use modified `i2o_controller`
3. Manual slicing and abstraction

3.1 Temporal Safety Spec.

```

global int allocstatus_c = 0;

event
{
  pattern
  { $? = i2o_iop_alloc(); }
  guard { allocstatus_c == 0 }
  action { allocstatus_c = 1; }
}

event
{
  pattern { i2o_iop_free($?); }
  guard { allocstatus_c == 1 }
  action { allocstatus_c = 0; }
}

event
{
  pattern { put_device($?); }
  guard { allocstatus_c == 1 }
}

```

- Preprocess source file
- Instrument code using `spec.opt`:

```

Fatal error: exception Failure
("Function declaration not
found")

```

3. One Case in Detail

```
static int i2o_pci_probe()
{
    struct i2o_controller *c;
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    c = i2o_iop_alloc();
    ...
    i2o_iop_free(c);
    ...
    put_device
    (c->device.parent);
    ...
    return rc;
}
```

1. Use a temporal safety specification

2. Manually add ERROR

label; use modified

i2o_controller

pblast.opt:

Error found!

The system is unsafe :-(

3.2 Problems

#1 Pointers in General

```
void i2o_iop_free
(struct i2o_controller *c)
{
    /* was: kfree(c); */

    if (c->alloc_status == 0)
        { goto ERROR; }
    else
        { c->alloc_status = 0;
          return; }

ERROR: return;
}
```

#2 Function Pointers

```
struct i2o_controller *
i2o_iop_alloc (void)
{ struct i2o_controller *c;
  ...
  c = kmalloc(sizeof(*c), ...);
  ...
  c->device.release =
    &i2o_iop_release;
  ...
  return c; }
```

3.2 Problems

#1 Pointers in General

```
void i2o_iop_free
(struct i2o_controller *c)
{
    /* was: kfree(c); */

    if (c->alloc_status == 0)
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    else
        { c->alloc_status = 0;
          return; }

ERROR: return;
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```

#2 Function Pointers

```
struct i2o_controller *
i2o_iop_alloc (void)
{ struct i2o_controller *c;
  ...
  c = kmalloc(sizeof(*c), ...);
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    &i2o_iop_release;
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  return c; }
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3. One Case in Detail

```
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    struct i2o_controller *c;
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    (c->device.parent);
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    return rc;
}
```

1. Use a temporal safety specification
2. Manually add ERROR label; use modified `i2o_controller`
3. Manual slicing and abstraction

4. Results

Memory Safety Error Type	Example							
	1	2	3	4	5	6	7	8
NULL de-reference				x				
use-after-free	x	x	x		x			
double free								x
overflow error						x		
pointer arithmetic							x	
involves concurrency					x			
Solved by	M	M	f	M	f	m	f	m

d = directly	m = minor modifications	M = manual abstraction	f = failed
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4. Results

Locking Properties Error Type	Example							
	1	2	3	4	5	6	7	8
deadlock condition	x	x	x	x		x	x	
other API violation					x			x
involves concurrency					x			x
Solved by	M	M	f	f	f	m	m	f

d = directly	m = minor modifications	M = manual abstraction	f = failed
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5. Conclusions

- + Good overall performance on modified source code
- + BLAST works much better for locking problems than for memory safety
- Modification of source code always required
- Non-support of pointers
- Lack of documentation
- Usability issues

6. Future Work

- Repeat the study once the demonstrated shortcomings of BLAST are resolved
- Develop metrics for a fair evaluation of software model checkers
- comparison with other tools such as MAGIC
- Conduct a study that allows one to draw quantitative conclusions

Thank you!

Further information:

<http://www.cs.york.ac.uk/~muehlber/blast/>

References

Beyer, D., Henzinger, T. A., Jhala, R., and Majumdar, R.: 2005, Checking memory safety with BLAST, in *FASE 2005*, Vol. 3442 of *LNCS*, pp 2–18

Corbet, J., Rubini, A., and Kroah-Hartmann, G.: 2005, *Linux Device Drivers*, O'Reilly, 3rd edition

Henzinger, T. A., Jhala, R., Majumdar, R., Necula, G. C., Sutre, G., and Weimer, W.: 2002, Temporal-safety proofs for systems code, in *CAV 2002*, Vol. 2404 of *LNCS*, pp 526–538