One Approach to Aspect-Oriented Programming Implementation for the C Programming Language

Evgenij Novikov
PhD student
Institute for System Programming, RAS
joker@ispras.ru

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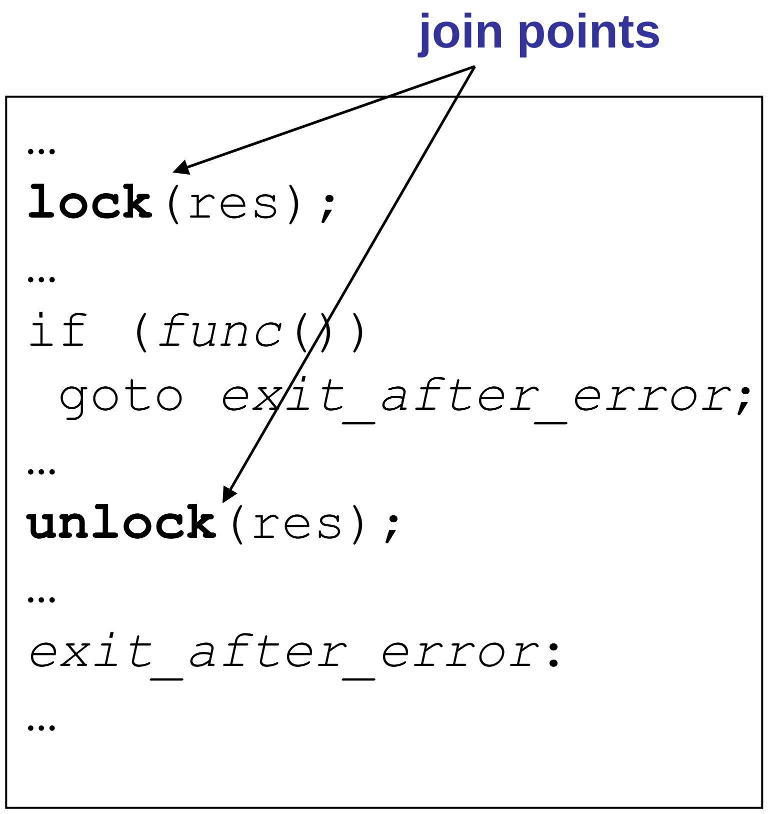
Aspect-oriented programming (1)

- Source code of a program

```
…
lock(res);
…
if (func())
 goto exit_after_error;
…
unlock(res);
…
exit_after_error:
…
```

Aspect-oriented programming (2)

- Source code of a program



```
…
lock(res);
…
if (func())
 goto exit_after_error;
…
unlock(res);
…
exit_after_error:
…
```

Aspect-oriented programming (3)

- Source code of a program

join points

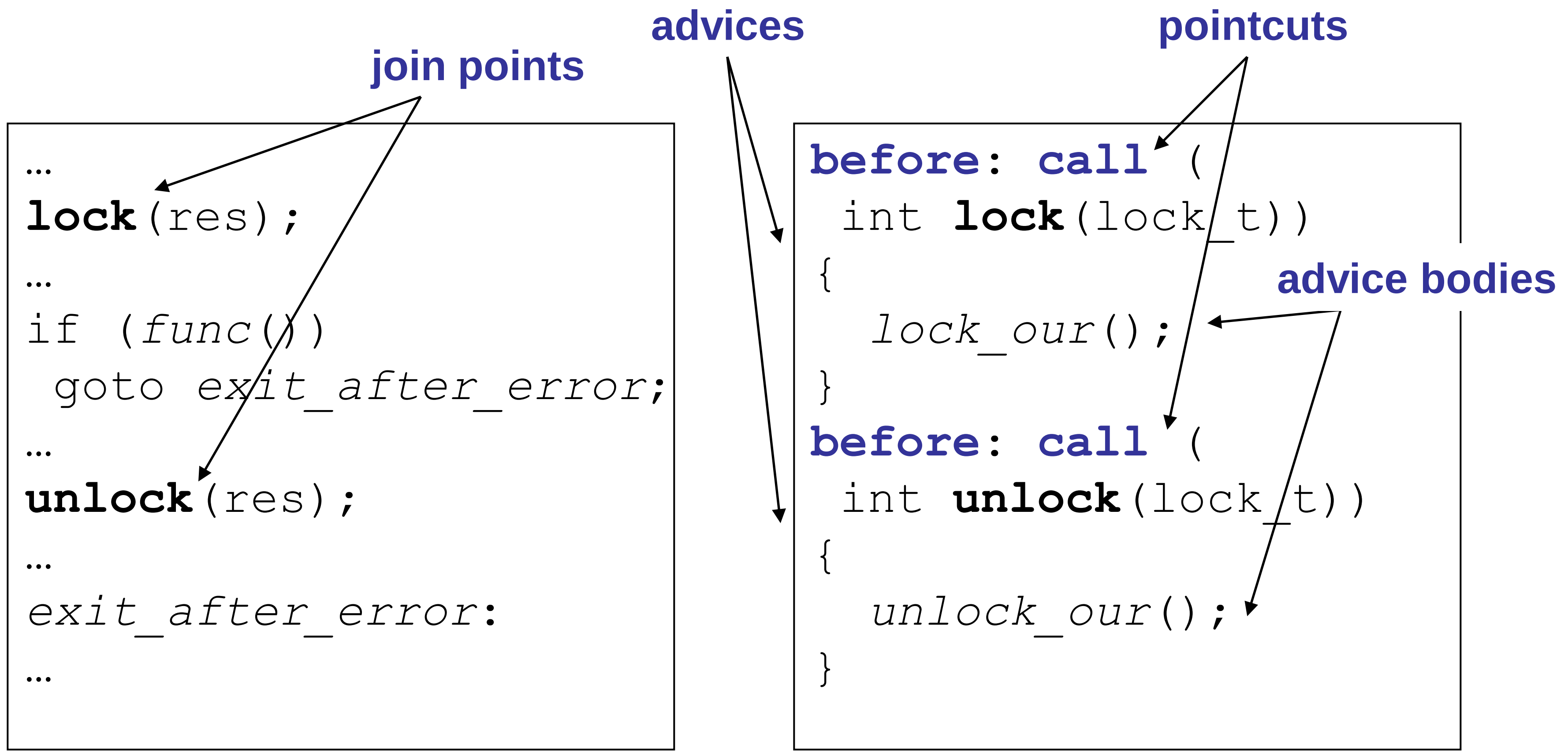
```
…
lock(res);
…
if (func())
 goto exit_after_error;
…
unlock(res);
…
exit_after_error:
…
```

- Aspect

```
before: call (
 int lock(lock_t))
{
  lock_our();
}
before: call (
 int unlock(lock_t))
{
  unlock_our();
}
```

Aspect-oriented programming (4)

- Source code of a program
- Aspect



```
…
lock(res);
…
if (func())
 goto exit_after_error;
…
unlock(res);
…
exit_after_error:
…
```

```
before: call (
 int lock(lock_t))
{
  lock_our();
}
before: call (
 int unlock(lock_t))
{
  unlock_our();
}
```

Instrumentation in AOP

- Instrumented source code of a program

```
…
lock_aux(res);
…
if (func())
 goto exit_after_error;
…
unlock_aux(res);
…
exit_after_error:
…
```

- Auxiliary routines

```
int lock_aux(lock_t a)
{
  lock_our();
  return lock(a);
}
int unlock_aux(lock_t a)
{
  unlock_our();
  return unlock(a);
}
```

AOP implementation

- AOP implementation depends on a programming language
- Different AOP implementations for a given programming language
  - determine their own syntax for AOP constructions
  - use different ways for source code instrumentation

Specific requirements of C

- Preprocessing
  - macro expansion and header files including as join points
- Compilation
  - a lot of “standard” join points like function calls, variable usage, …
  - specific join points concerned with pointer operations of C
- Linking
  - different object files to be linked shouldn’t contain the same defined symbols

Requirements of real application

- Support the standard C with all GNU extensions
- Offer a large set of AOP constructions
- Generate instrumented C source code equivalent to the original one
- Rather easy maintenance

Related work

	ACC	InterAspect	SLIC
“Preprocessing”	-	-	-
“Compilation”	±	∓	∓
“Linking”	-	-	+
C with GNU extensions	±	+	±
C output	+	-	+
Maintenance	-	±	+

Suggested approach (1)

- Aspect preprocessing (1st stage)

Initial source code

```
…
lock(res);
…
unlock(res);
…
```

+

Aspect

```
before: file (
 $this)
{
#include "aux.h"
int lock_flag = 0;
}
```

=

Resulting source code

```
#include "aux.h"
int lock_flag = 0;
…
lock(res);
…
unlock(res);
…
```

Suggested approach (2)

- Macro weaving (2nd stage)

Source code

```
#define LOCK(t) …
#define UNLOCK(t)
 unlock(t)
…
LOCK(res);
…
UNLOCK(res);
…
```

+

Aspect

```
around: define (
 LOCK(t))
{
lock_our()
}
```

=

Preprocessed source code

```
…
lock_our();
…
unlock(res);
…
```

Suggested approach (3)

- Advice weaving (3rd stage)

Preprocessed source code

```
…
lock(res);
…
unlock(res);
…
```

+

Aspect

```
before: call (
 int lock
  (lock_t))
{
  lock_our();
}
```

=

Resulting source code

```
…
lock(res);
…
unlock(res);
…
int lock_aux_1
  (loct_t a) {
   lock_our();
   return lock(a);
}
```

Suggested approach (4)

- Compilation (4th stage)

Preprocessed source code

```
…
lock(res);
…
unlock(res);
…
int lock_aux_1
 (loct_t a) {
  lock_our();
  return lock(a);
}
```

+

Aspect

```
before: call (
 int lock
  (lock_t))
{
  lock_our();
}
```

=

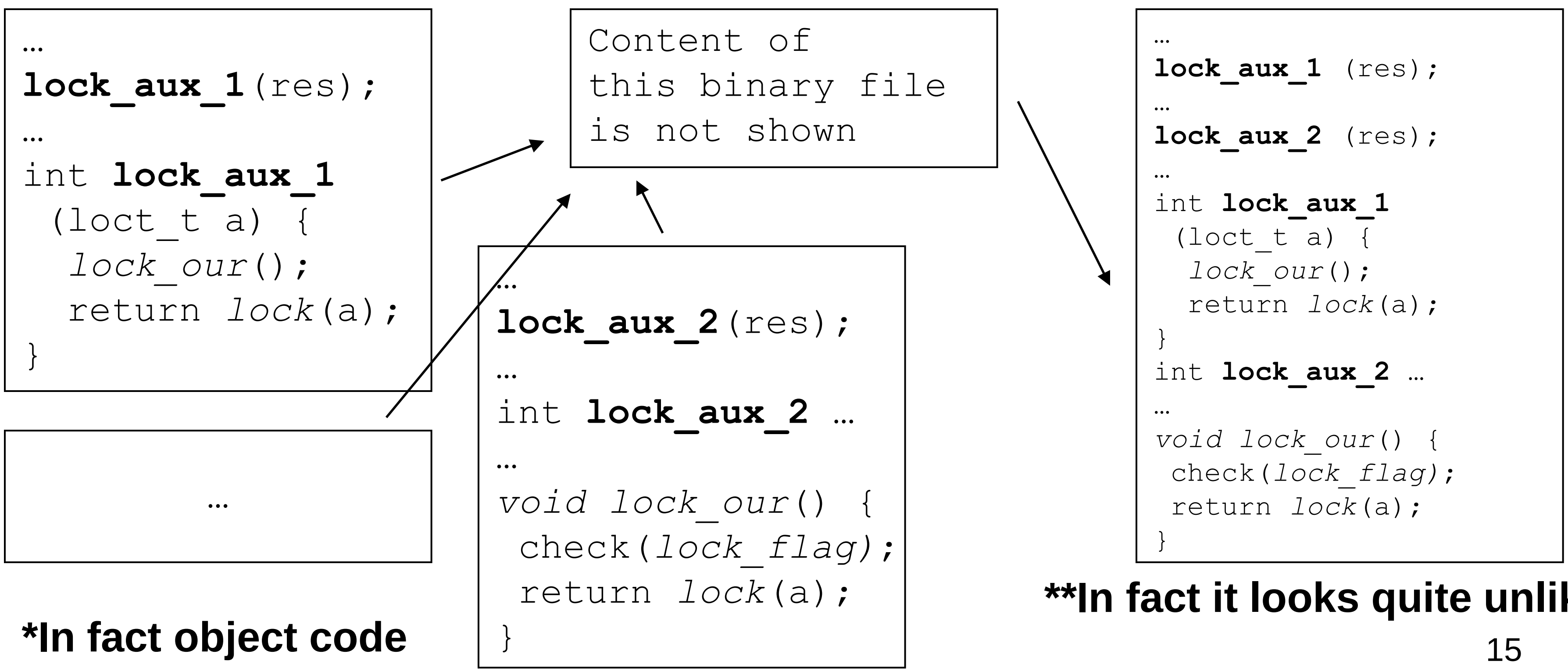
Resulting source code*

```
…
lock_aux_1(res);
…
unlock(res);
…
int lock_aux_1
 (loct_t a) {
  lock_our();
  return lock(a);
}
```

***In fact object code**

Suggested approach (5)

- Linking and C code generating (final stages)



Source code*

```
…
lock_aux_1(res);
…
int lock_aux_1
 (loct_t a) {
  lock_our();
  return lock(a);
}
```

```
…
```

Linked file

```
Content of
this binary file
is not shown
```

```
…
lock_aux_2(res);
…
int lock_aux_2 …
…
void lock_our() {
 check(lock_flag);
 return lock(a);
}
```

Resulting source code**

```
…
lock_aux_1 (res);
…
lock_aux_2 (res);
…
int lock_aux_1
 (loct_t a) {
  lock_our();
  return lock(a);
}
int lock_aux_2 …
…
void lock_our() {
 check(lock_flag);
 return lock(a);
}
```

***In fact object code**

****In fact it looks quite unlike**

Approbation

- Drivers of Linux kernel 2.6.31.6 were instrumented by means of a tool implementing the suggested approach
  - a model concerned with mutex lock/unlock rule was used
  - almost all 2160 modules were processed successfully
- Subsequent static verification showed that the tool behaves rather well
  - more memory is required in comparison with manual instrumentation
  - generated constructions are even simpler as original ones
- Generated source code is too inconvenient for static verifiers and analysis

Conclusion

- It was developed the new approach of C AOP implementation that covers specific requirements of both the C programming language and real AOP application
- The tool implementing the suggested approach successfully works

- It is required a new way to generate C source code
- More AOP constructions like C pointer operations should be supported

Thank you!
Questions?

http://forge.ispras.ru/projects/ldv

joker@ispras.ru

drivers/pci/hotplug/fakephp.c
(preprocessed)

```
if (strict_strtoul(buf, 0, &val) < 0)
  return -22;
if (val)
  pci_rescan_bus(slot->dev->bus);
```

fakephp.ko.linked.cbe.c

```
blast_must_tmp__85 = *(&llvm_cbe_buf_addr);
blast_must_tmp__86 = strict_strtoul(blast_must_tmp__85,
    0u, (&llvm_cbe_val));
if ((((signed int )blast_must_tmp__86) < ((signed int
    )0u)))
  goto llvm_cbe_bb;
else
  goto llvm_cbe_bb1;
llvm_cbe_bb:
  *(&llvm_cbe_tmp__73) = 18446744073709551594ull;
  goto llvm_cbe_bb5;
llvm_cbe_bb1:
  blast_must_tmp__87 = *(&llvm_cbe_val);
  blast_must_tmp__88 = *(&llvm_cbe_slot);
  blast_must_tmp__89 = *((&blast_must_tmp__88->field1));
if ((blast_must_tmp__87 != 0ull))
  goto llvm_cbe_bb2;
else
  goto llvm_cbe_bb3;
llvm_cbe_bb2:
  blast_must_tmp__90 = *((&blast_must_tmp__89->field1));
  blast_must_tmp__91 =
    pci_rescan_bus(blast_must_tmp__90);
llvm_cbe_bb3:
…
```