Konfigurierbare Systemsoftware (KSS)

VL 3 – Aspect-Oriented Programming (AOP)

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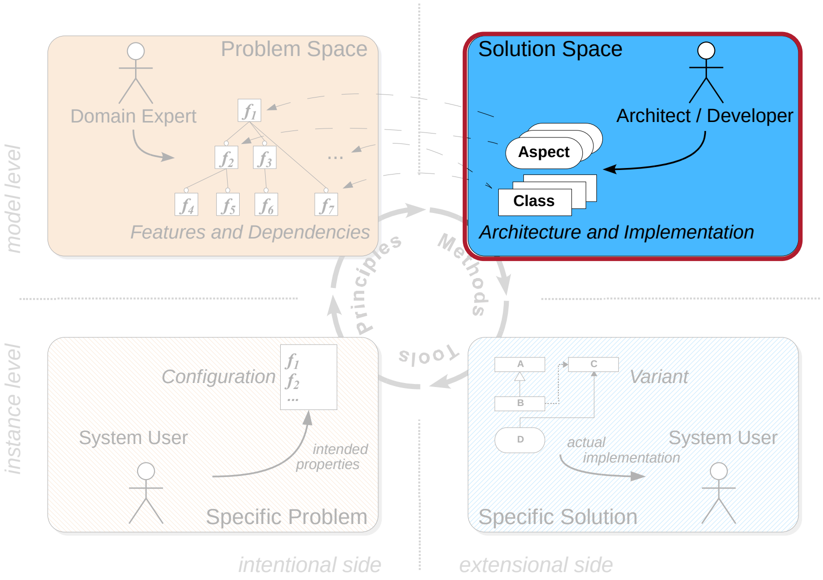
SS 12 – 2012-05-23

http://www4.informatik.uni-erlangen.de/Lehre/SS12/V_KSS

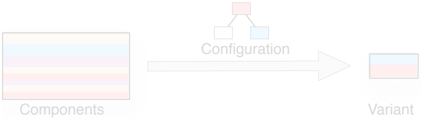
03-AspectC++_handout

About this Lecture



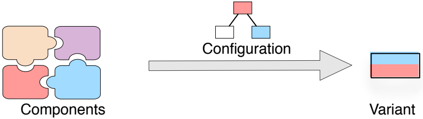
Implementation Techniques: Classification

- Decompositional Approaches



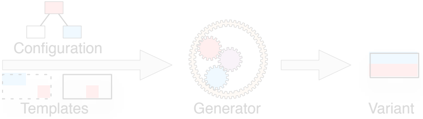
  - Text-based filtering (untyped)
  - Preprocessors

- Compositional Approaches



  - Language-based composition mechanisms (typed)
  - OOP, **AOP**, Templates

- Generative Approches



  - Metamodel-based generation of components (typed)
  - MDD, C++ TMP, generators

Agenda

3.1 Motivation: Separation of Concerns

3.2 Tutorial: AspectC++

3.3 Summary and Outlook

3.4 References

Agenda

3.1 Motivation: Separation of Concerns

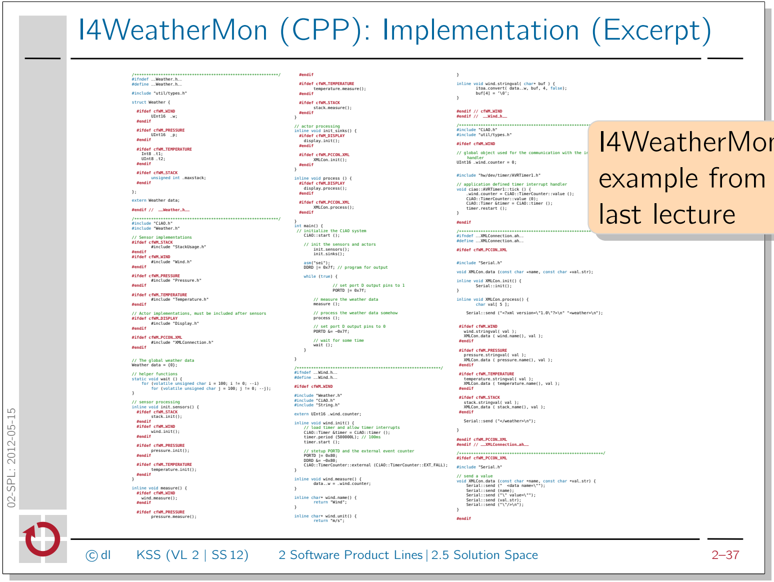
- Example: I4WeatherMon
- Example: eCos
- AOP

3.2 Tutorial: AspectC++

3.3 Summary and Outlook

3.4 References

Static Configurability with the CPP?



I4WeatherMon (CPP): Implementation (Excerpt)

```
/*************************************************************/
#ifndef __Weather_h__
#define __Weather_h__

#include "util/types.h"

struct Weather {

  #ifdef cfWM_WIND
        UInt16  _w;
  #endif

  #ifdef cfWM_PRESSURE
        UInt16  _p;
  #endif

  #ifdef cfWM_TEMPERATURE
    Int8 _t1;
    UInt8 _t2;
  #endif

  #ifdef cfWM_STACK
        unsigned int _maxstack;
  #endif

};

extern Weather data;

#endif //  __Weather_h__

/*************************************************************/
#include "CiAO.h"
#include "Weather.h"

// Sensor implementations
#ifdef cfWM_STACK
        #include "StackUsage.h"
#endif
#ifdef cfWM_WIND
        #include "Wind.h"
#endif

#ifdef cfWM_PRESSURE
        #include "Pressure.h"
#endif

#ifdef cfWM_TEMPERATURE
        #include "Temperature.h"
#endif

// Actor implementations, must be included after sensors
#ifdef cfWM_DISPLAY
        #include "Display.h"
#endif

#ifdef cfWM_PCCON_XML
        #include "XMLConnection.h"
#endif


// The global weather data
Weather data = {0};

// helper functions
static void wait () {
    for (volatile unsigned char i = 100; i != 0; --i)
        for (volatile unsigned char j = 100; j != 0; --j);
}

// sensor processing
inline void init_sensors() {
  #ifdef cfWM_STACK
        stack_init();
  #endif
  #ifdef cfWM_WIND
        wind_init();
  #endif

  #ifdef cfWM_PRESSURE
        pressure_init();
  #endif

  #ifdef cfWM_TEMPERATURE
        temperature_init();
  #endif
}

inline void measure() {
  #ifdef cfWM_WIND
    wind_measure();
  #endif

  #ifdef cfWM_PRESSURE
        pressure_measure();
  #endif

  #ifdef cfWM_TEMPERATURE
        temperature_measure();
  #endif

  #ifdef cfWM_STACK
        stack_measure();
  #endif
}

// actor processing
inline void init_sinks() {
  #ifdef cfWM_DISPLAY
    display_init();
  #endif

  #ifdef cfWM_PCCON_XML
        XMLCon_init();
  #endif
}

inline void process () {
  #ifdef cfWM_DISPLAY
    display_process();
  #endif

  #ifdef cfWM_PCCON_XML
        XMLCon_process();
  #endif

}
int main() {
 // initialize the CiAO system
    CiAO::start ();

    // init the sensors and actors
        init_sensors();
        init_sinks();

    asm("sei");
    DDRD |= 0x7f; // program for output

    while (true) {

            // set port D output pins to 1
            PORTD |= 0x7f;

        // measure the weather data
        measure ();

        // process the weather data somehow
        process ();

        // set port D output pins to 0
        PORTD &= ~0x7f;

        // wait for some time
        wait ();
    }

}

/*************************************************************/
#ifndef __Wind_h__
#define __Wind_h__

#ifdef cfWM_WIND

#include "Weather.h"
#include "CiAO.h"
#include "String.h"

extern UInt16 _wind_counter;

inline void wind_init() {
    // load timer and allow timer interrupts
    CiAO::Timer &timer = CiAO::timer ();
    timer.period (500000L); // 100ms
    timer.start ();

    // stetup PORTD and the external event counter
    PORTD |= 0x80;
    DDRD &= ~0x80;
    CiAO::TimerCounter::external (CiAO::TimerCounter::EXT_FALL);
}

inline void wind_measure() {
        data._w = _wind_counter;
}

inline char* wind_name() {
        return "Wind";
}

inline char* wind_unit() {
        return "m/s";
}

inline void wind_stringval( char* buf ) {
        itoa_convert( data._w, buf, 4, false);
        buf[4] = '\0';
}


#endif // cfWM_WIND
#endif //  __Wind_h__

/******************************************************
#include "CiAO.h"
#include "util/types.h"

#ifdef cfWM_WIND

// global object used for the communication with the in
    handler
UInt16 _wind_counter = 0;


#include "hw/dev/timer/AVRTimer1.h"

// application defined timer interrupt handler
void ciao::AVRTimer1::tick () {
    _wind_counter = CiAO::TimerCounter::value ();
    CiAO::TimerCounter::value (0);
    CiAO::Timer &timer = CiAO::timer ();
    timer.restart ();
}

#endif

/******************************************************
#ifndef __XMLConnection_ah__
#define __XMLConnection_ah__

#ifdef cfWM_PCCON_XML


#include "Serial.h"

void XMLCon_data (const char *name, const char *val_str);

inline void XMLCon_init() {
        Serial::init();
}

inline void XMLCon_process() {
        char val[ 5 ];

    Serial::send ("<?xml version=\"1.0\"?>\n" "<weather>\n");


 #ifdef cfWM_WIND
   wind_stringval( val );
   XMLCon_data ( wind_name(), val );
 #endif

 #ifdef cfWM_PRESSURE
   pressure_stringval( val );
   XMLCon_data ( pressure_name(), val );
 #endif

 #ifdef cfWM_TEMPERATURE
   temperature_stringval( val );
   XMLCon_data ( temperature_name(), val );
 #endif

 #ifdef cfWM_STACK
   stack_stringval( val );
   XMLCon_data ( stack_name(), val );
 #endif

   Serial::send ("</weather>\n");

}

#endif cfWM_PCCON_XML
#endif // __XMLConnection_ah__

/*************************************************************/
#ifdef cfWM_PCCON_XML

#include "Serial.h"

// send a value
void XMLCon_data (const char *name, const char *val_str) {
    Serial::send ("  <data name=\"");
    Serial::send (name);
    Serial::send ("\" value=\"");
    Serial::send (val_str);
    Serial::send ("\"/>\n");
}

#endif
```

02-SPL: 2012-05-15

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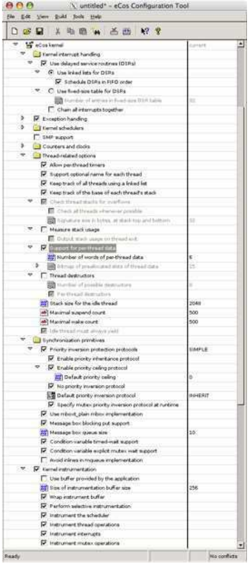
I4WeatherMon example from last lecture

Case Study eCos [4]

- The **e**mbedded **C**onfigurable **o**perating **s**ystem
  - Operating system for embedded applications
  - Open source, maintained by eCosCentric Inc.
  - Many 16-bit and 32-bit platforms supported
  - Broadly accepted real-world system
- More than **750** configuration options (kernel)
  - Feature-based selection
  - **Preprocessor-based** implementation



untitled* – eCos Configuration Tool

```
▾ eCos kernel                                                   current
  ▾ Kernel interrupt handling
    ▾ ☑ Use delayed service routines (DSRs)
      ▾ ● Use linked lists for DSRs
          ☑ Schedule DSRs in FIFO order
      ▾ ○ Use fixed-size table for DSRs
          Number of entries in fixed-size DSR table             32
        □ Chain all interrupts together
  ▸ ☑ Exception handling
  ▸ Kernel schedulers
    □ SMP support
  ▸ Counters and clocks
  ▾ Thread-related options
      ☑ Allow per-thread timers
      ☑ Support optional name for each thread
      ☑ Keep track of all threads using a linked list
      ☑ Keep track of the base of each thread's stack
    ▾ ☑ Check thread stacks for overflows
        ☑ Check all threads whenever possible
        Signature size in bytes, at stack top and bottom        32
    ▾ □ Measure stack usage
        ☑ Output stack usage on thread exit
    ▾ ☑ Support for per-thread data
        Number of words of per-thread data                      6
      ▸ Bitmap of preallocated slots of thread data             15
    ▾ □ Thread destructors
        Number of possible destructors                          8
        ☑ Per-thread destructors
      Stack size for the idle thread                            2048
      Maximal suspend count                                     500
      Maximal wake count                                        500
      ☑ Idle thread must always yield
  ▾ Synchronization primitives
    ▾ ☑ Priority inversion protection protocols                 SIMPLE
        ☑ Enable priority inheritance protocol
      ▾ ☑ Enable priority ceiling protocol
          Default priority ceiling                              0
        ☑ No priority inversion protocol
        Default priority inversion protocol                     INHERIT
        ☑ Specify mutex priority inversion protocol at runtime
      ☑ Use mboxt_plain mbox implementation
      ☑ Message box blocking put support
      Message box queue size                                    10
      ☑ Condition variable timed-wait support
      ☑ Condition variable explicit mutex wait support
      □ Avoid inlines in mqueue implementation
  ▾ ☑ Kernel instrumentation
      □ Use buffer provided by the application
      Size of instrumentation buffer size                       256
      ☑ Wrap instrument buffer
      ☑ Perform selective instrumentation
      ☑ Instrument the scheduler
      ☑ Instrument thread operations
      ☑ Instrument interrupts
      ☑ Instrument mutex operations
Ready                                                           No conflicts
```

Static Configurability with the CPP?

```
Cyg_Mutex::Cyg_Mutex() {
  CYG_REPORT_FUNCTION();
  locked      = false;
  owner       = NULL;
#if defined(CYGSEM_KERNEL_SYNCH_MUTEX_PRIORITY_INVERSION_PROTOCOL_DEFAULT) && \
  defined(CYGSEM_KERNEL_SYNCH_MUTEX_PRIORITY_INVERSION_PROTOCOL_DYNAMIC)
#ifdef CYGSEM_KERNEL_SYNCH_MUTEX_PRIORITY_INVERSION_PROTOCOL_DEFAULT_INHERIT
  protocol    = INHERIT;
#endif
#ifdef CYGSEM_KERNEL_SYNCH_MUTEX_PRIORITY_INVERSION_PROTOCOL_DEFAULT_CEILING
  protocol    = CEILING;
  ceiling     = CYGSEM_KERNEL_SYNCH_MUTEX_PRIORITY_INVERSION_PROTOCOL_DEFAULT_PRIORITY;
#endif
#ifdef CYGSEM_KERNEL_SYNCH_MUTEX_PRIORITY_INVERSION_PROTOCOL_DEFAULT_NONE
  protocol    = NONE;
#endif
#else // not (DYNAMIC and DEFAULT defined)
#ifdef CYGSEM_KERNEL_SYNCH_MUTEX_PRIORITY_INVERSION_PROTOCOL_CEILING
#ifdef CYGSEM_KERNEL_SYNCH_MUTEX_PRIORITY_INVERSION_PROTOCOL_DEFAULT_PRIORITY
  // if there is a default priority ceiling defined, use that to initialize
  // the ceiling.
  ceiling = CYGSEM_KERNEL_SYNCH_MUTEX_PRIORITY_INVERSION_PROTOCOL_DEFAULT_PRIORITY;
#else
  // Otherwise set it to zero.
  ceiling = 0;
#endif
#endif
#endif // DYNAMIC and DEFAULT defined
  CYG_REPORT_RETURN();
}
```

Mutex options:

PROTOCOL

CEILING

INHERIT

DYNAMIC

Kernel policies: Tracing Instrumentation Synchronization

Static Configurability with the CPP?

```
Cyg_Mutex::Cyg_Mutex() {
  CYG_REPORT_FUNCTION();
  locked      = false;
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#if defined(CYGSEM_KERNEL_SYNCH_MUTEX_PRIORITY_INVERSION_PROTOCOL_DEFAULT) && \
  defined(CYGSEM_KERNEL_SYNCH_MUTEX_PRIORITY_INVERSION_PROTOCOL_DYNAMIC)
#ifdef CYGSEM_KERNEL_SYNCH_MUTEX_PRIORITY_INVERSION_PROTOCOL_DEFAULT_INHERIT
  protocol    = INHERIT;
#endif
#ifdef CYGSEM_KERNEL_SYNCH_MUTEX_PRIORITY_INVERSION_PROTOCOL_DEFAULT_CEILING
  protocol    = CEILING;
  ceiling     = CYGSEM_                                    N_PROTOCOL_DEFAULT_PRIORITY;
#endif
#ifdef CYGSEM_KERNEL_SY                                    L_DEFAULT_NONE
  protocol    = NONE;
#endif
#else // not (DYNAMIC a
#ifdef CYGSEM_KERNEL_SY                                    L_CEILING
#ifdef CYGSEM_KERNEL_SYNCH_MUTEX_PRIORITY_INVERSION_PROTOCOL_DEFAULT_PRIORITY
  // if there is a default priority ceiling defined, use that to initialize
  // the ceiling.
  ceiling = CYGSEM_KERNEL_SYNCH_MUTEX_PRIORITY_INVERSION_PROTOCOL_DEFAULT_PRIORITY;
#else
  // Otherwise set it to zero.
  ceiling = 0;
#endif
#endif
#endif // DYNAMIC and DEFAULT defined
  CYG_REPORT_RETURN();
}
```

```
Cyg_Mutex::Cyg_Mutex() {
  locked      = false;
  owner       = NULL;
}
```

Mutex options:

PROTOCOL

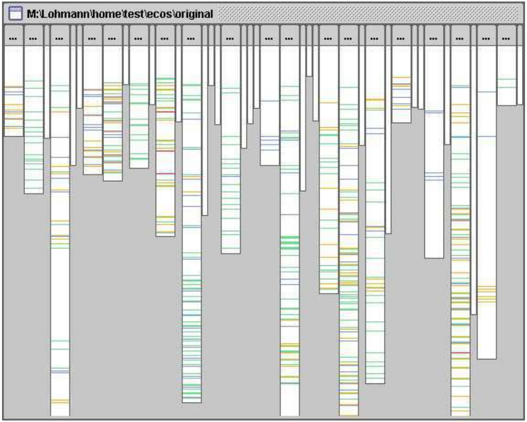
CEILING

INHERIT

DYNAMIC

Kernel policies: Tracing Instrumentation Synchronization

Static Configurability with the CPP?



Mutex options:

PROTOCOL

CEILING

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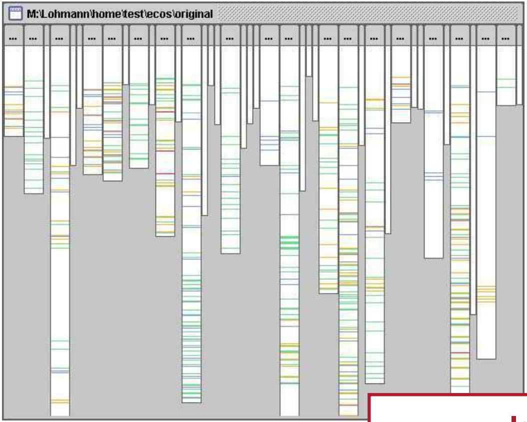
Kernel policies: Tracing Instrumentation Synchronization

Static Configurability with the CPP?



Mutex options:

PROTOCOL

CEILING

INHERIT

DYNAMIC

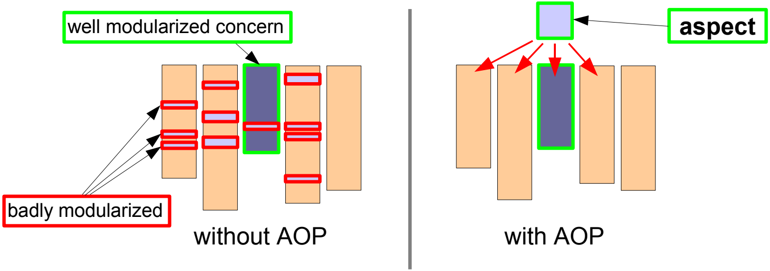
Issue

Crosscutting Concerns

Kernel policies: Tracing Instrumentation Synchronization

Aspect-Oriented Programming

- AOP is about modularizing crosscutting concerns



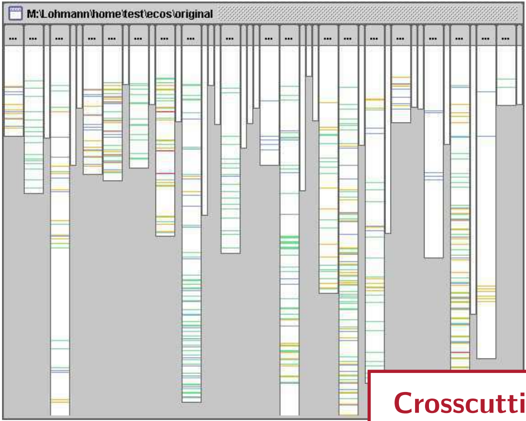
- Examples: tracing, synchronization, security, buffering, error handling, constraint checks, ...

AOP: The Basic Idea

Separation of **what** from **where**:

- **Join Points** ↦ **where**
  - positions in the static structure or dynamic control flow (event)
  - given declaratively by pointcut expressions
- **Advice** ↦ **what**
  - additional elements (members, ...) to introduce at join points
  - additional behavior (code) to superimpose at join points

Static Configurability with the CPP?



Mutex options:

PROTOCOL

CEILING

INHERIT

DYNAMIC

Crosscutting Concerns

Can we do better with aspects?

Kernel policies: Tracing Instrumentation Synchronization

Implementation of Crosscutting Concerns with AOP

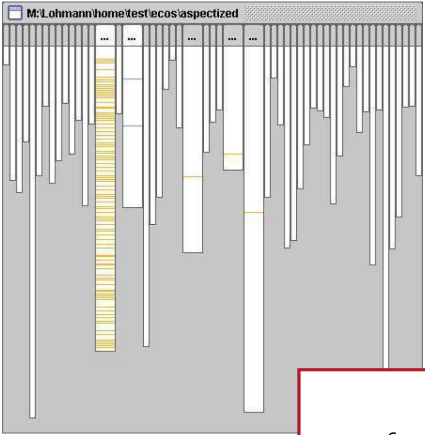
```
aspect int_sync {

  pointcut sync() = execution(…) // kernel calls to sync
          || construction(…)
          || destruction(…);

  // advise kernel code to invoke lock() and unlock()
  advice sync() : before() {
    Cyg_Scheduler::lock();
  }
  advice sync() : after() {
    Cyg_Scheduler::unlock();
  }

  // In eCos, a new thread always starts with a lock value of 0
  advice execution(
  "%Cyg_HardwareThread::thread_entry(...)") : before() {
    Cyg_Scheduler::zero_sched_lock();
  }
  …
};
```

where

what

Synchronization

Static Configurability with the CPP?



Result

after refactoring into aspects [4]

Kernel policies: Tracing Instrumentation Synchronization

AspectC++ [5, 6]

- AspectC++ is an AOP language extension for C++
  - superset of ISO C++ 98 [1]

    ⇝ every C++ program is also an AspectC++ program
  - additionally supports AOP concepts
- Technical approach: source-to-source transformation
  - **ac++** *weaver* transforms AspectC++ code into C++ code
  - resulting C++ code can be compiled with any standard-compliant compiler (especially gcc)
  - **ag++** *weaver wrapper* works as replacement for **g++** in makefiles
- Language and weaver are open source (GPL2)

`http://www.aspectc.org`

Agenda

3.1 Motivation: Separation of Concerns

3.2 Tutorial: AspectC++

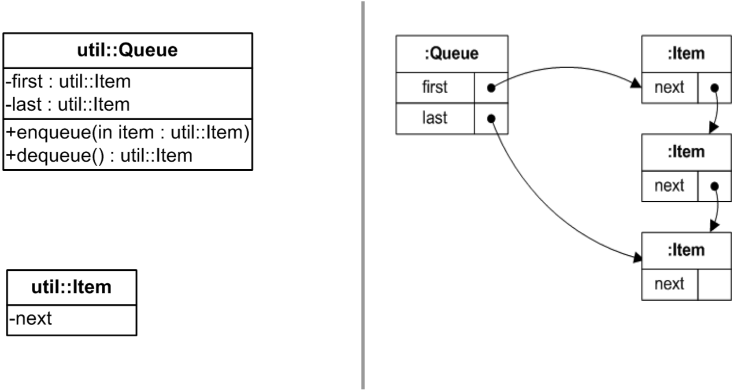
- Example Szenario
- First Steps And Language Overview
- Advanced Concepts
- Weaver Transformations
- Further Examples

3.3 Summary and Outlook

3.4 References

Scenario: A Simple Queue

Scenario: A Queue utility class



util::Queue

-first : util::Item
-last : util::Item

+enqueue(in item : util::Item)
+dequeue() : util::Item

util::Item

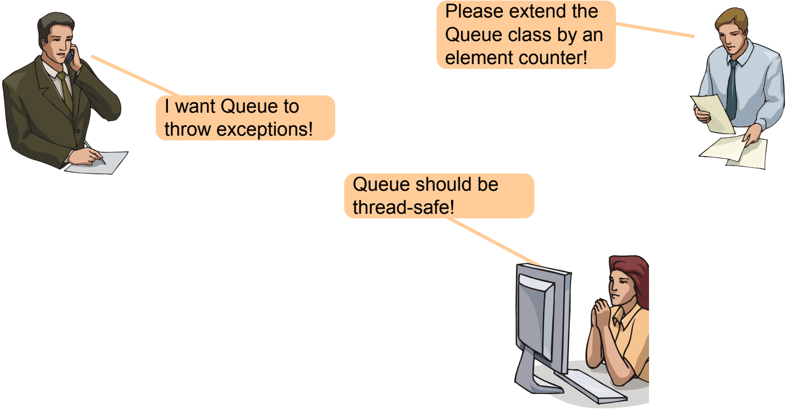
-next

The Simple Queue Class

```
namespace util {
  class Item {
    friend class Queue;
    Item* next;
  public:
    Item() : next(0){}
  };

  class Queue {
    Item* first;
    Item* last;
  public:
    Queue() : first(0), last(0) {}

    void enqueue( Item* item ) {
      printf( "  > Queue::enqueue()\n" );
      if( last ) {
        last->next = item;
        last = item;
      } else
        last = first = item;
      printf( "  < Queue::enqueue()\n" );
    }
    Item* dequeue() {
      printf("  > Queue::dequeue()\n");
      Item* res = first;
      if( first == last )
        first = last = 0;
      else
        first = first->next;
      printf("  < Queue::dequeue()\n");
      return res;
    }
  }; // class Queue
} // namespace util
```

Scenario: The Problem

Various users of Queue demand extensions:



I want Queue to throw exceptions!

Please extend the Queue class by an element counter!

Queue should be thread-safe!

The Not So Simple Queue Class

```
class Queue {
  Item *first, *last;
  int counter;
  os::Mutex lock;
public:
  Queue () : first(0), last(0) {
    counter = 0;
  }
  void enqueue(Item* item) {
    lock.enter();
    try {
      if (item == 0)
        throw QueueInvalidItemError();
      if (last) {
        last->next = item;
        last = item;
      } else { last = first = item; }
      ++counter;
    } catch (...) {
      lock.leave(); throw;
    }
    lock.leave();
  }
```

```
  Item* dequeue() {
    Item* res;
    lock.enter();
    try {
      res = first;
      if (first == last)
        first = last = 0;
      else first = first->next;
      if (counter > 0) -counter;
      if (res == 0)
        throw QueueEmptyError();
    } catch (...) {
      lock.leave();
      throw;
    }
    lock.leave();
    return res;
  }
  int count() { return counter; }
}; // class Queue
```

What Code Does What?

```
class Queue {
  Item *first, *last;
  int counter;
  os::Mutex lock;
public:
  Queue () : first(0), last(0) {
    counter = 0;
  }
  void enqueue(Item* item) {
    lock.enter();
    try {
      if (item == 0)
        throw QueueInvalidItemError();
      if (last) {
        last->next = item;
        last = item;
      } else { last = first = item; }
      ++counter;
    } catch (...) {
      lock.leave(); throw;
    }
    lock.leave();
  }
```

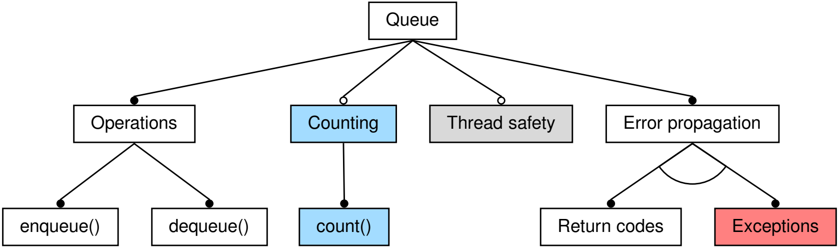
```
  Item* dequeue() {
    Item* res;
    lock.enter();
    try {
      res = first;
      if (first == last)
        first = last = 0;
      else first = first->next;
      if (counter > 0) –counter;
      if (res == 0)
        throw QueueEmptyError();
    } catch (...) {
      lock.leave();
      throw;
    }
    lock.leave();
    return res;
  }
  int count() { return counter; }
}; // class Queue
```

Problem Summary

The component code is “polluted” with code for several logically independent concerns, thus it is ...

- hard to **write** the code
  - many different things have to be considered simultaneously
- hard to **read** the code
  - many things are going on at the same time
- hard to **maintain** and **evolve** the code
  - the implementation of concerns such as locking is **scattered** over the entire source base (a “*crosscutting concern*”)
- hard to **configure** at compile time
  - the users get a “one fits all” queue class

Goal: A configurable Queue



Goal: A configurable Queue

Configuring with the Preprocessor?

```
class Queue {
  Item *first, *last;
#ifdef COUNTING_ASPECT
  int counter;
#endif
#ifdef LOCKING_ASPECT
  os::Mutex lock;
#endif
public:
  Queue () : first(0), last(0) {
#ifdef COUNTING_ASPECT
    counter = 0;
#endif
  }
  void enqueue(Item* item) {
#ifdef LOCKING_ASPECT
    lock.enter();
    try {
#endif
#ifdef ERRORHANDLING_ASPECT
      if (item == 0)
        throw QueueInvalidItemError();
#endif
      if (last) {
        last->next = item;
        last = item;
      } else { last = first = item; }
#ifdef COUNTING_ASPECT
      ++counter;
#endif
#ifdef LOCKING_ASPECT
    } catch (...) {
      lock.leave(); throw;
    }
    lock.leave();
#endif
  }
```

```
  Item* dequeue() {
    Item* res;
#ifdef LOCKING_ASPECT
    lock.enter();
    try {
#endif
      res = first;
      if (first == last)
        first = last = 0;
      else first = first->next;
#ifdef COUNTING_ASPECT
      if (counter > 0) --counter;
#endif
#ifdef ERRORHANDLING_ASPECT
      if (res == 0)
        throw QueueEmptyError();
#endif
#ifdef LOCKING_ASPECT
    } catch (...) {
      lock.leave();
      throw;
    }
    lock.leave();
#endif
    return res;
  }
#ifdef COUNTING_ASPECT
  int count() { return counter; }
#endif
}; // class Queue
```

Agenda

3.1 Motivation: Separation of Concerns

3.2 Tutorial: AspectC++

- Example Szenario
- First Steps And Language Overview
- Advanced Concepts
- Weaver Transformations
- Further Examples

3.3 Summary and Outlook

3.4 References

Queue: Demanded Extensions

I. Element counting

Please extend the Queue class by an element counter!

II. Errorhandling
(signaling of errors by exceptions)

III. Thread safety
(synchronization by mutex variables)

Queue: Element Counting

Element counting: The Idea

- Increment a counter variable after each execution of `util::Queue::enqueue()`
- Decrement it after each execution of `util::Queue::dequeue()`

03-AspectC++_handout

Queue: Element Counting

ElementCounter1

```
aspect ElementCounter {

  int counter;
  ElementCounter() {
    counter = 0;
  }

  advice execution("% util::Queue::enqueue(...)") : after() {
    ++counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", counter );
  }
  advice execution("% util::Queue::dequeue(...)") : after() {
    if( counter > 0 ) --counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", counter );
  }
};
```

ElementCounter1.ah

Queue: Element Counting

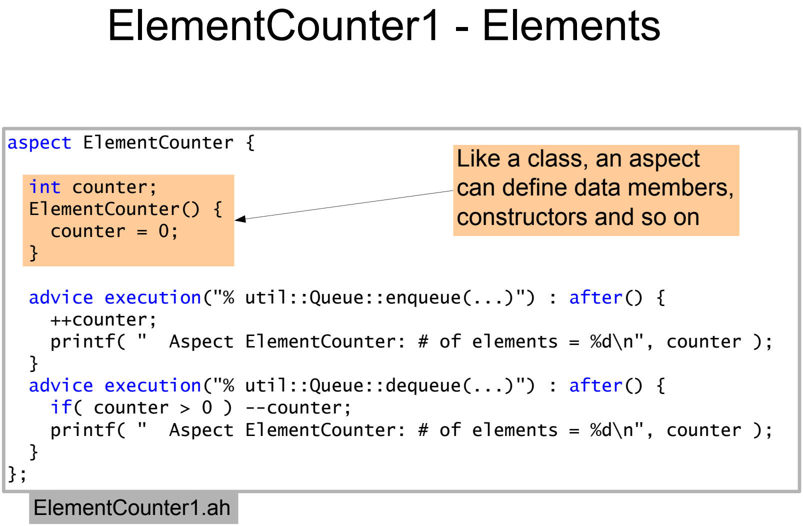
ElementCounter1 - Elements

```
aspect ElementCounter {

  int counter;
  ElementCounter() {
    counter = 0;
  }

  advice execution("% util::Queue::enqueue(...)") : after() {
    ++counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", counter );
  }
  advice execution("% util::Queue::dequeue(...)") : after() {
    if( counter > 0 ) --counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", counter );
  }
};
```

We introduced a new **aspect** named *ElementCounter*.
An aspect starts with the keyword aspect and is syntactically much like a class.

ElementCounter1.ah

Queue: Element Counting



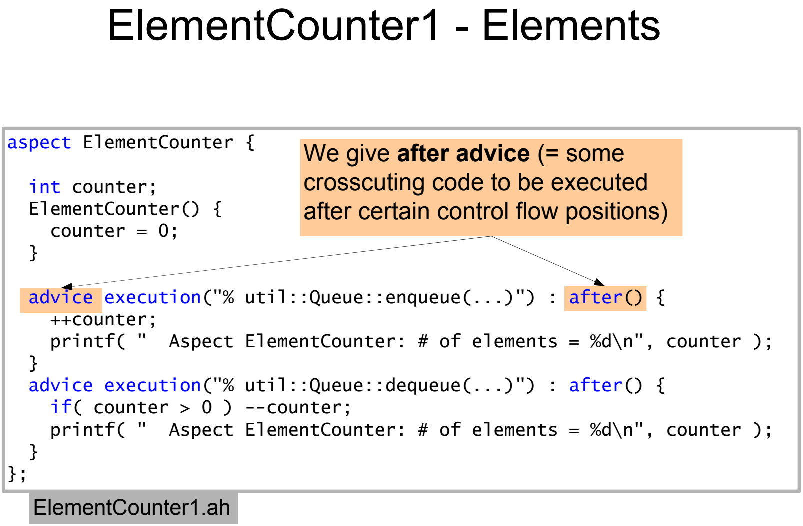
ElementCounter1 - Elements

```
aspect ElementCounter {

  int counter;
  ElementCounter() {
    counter = 0;
  }

  advice execution("% util::Queue::enqueue(...)") : after() {
    ++counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", counter );
  }
  advice execution("% util::Queue::dequeue(...)") : after() {
    if( counter > 0 ) --counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", counter );
  }
};
```

Like a class, an aspect can define data members, constructors and so on

ElementCounter1.ah

Queue: Element Counting



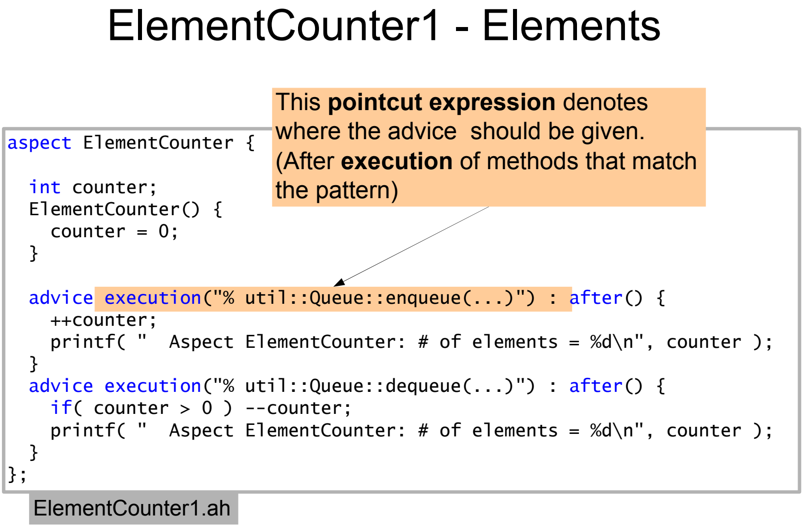
ElementCounter1 - Elements

We give **after advice** (= some crosscuting code to be executed after certain control flow positions)

```
aspect ElementCounter {

  int counter;
  ElementCounter() {
    counter = 0;
  }

  advice execution("% util::Queue::enqueue(...)") : after() {
    ++counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", counter );
  }
  advice execution("% util::Queue::dequeue(...)") : after() {
    if( counter > 0 ) --counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", counter );
  }
};
```

ElementCounter1.ah

Queue: Element Counting



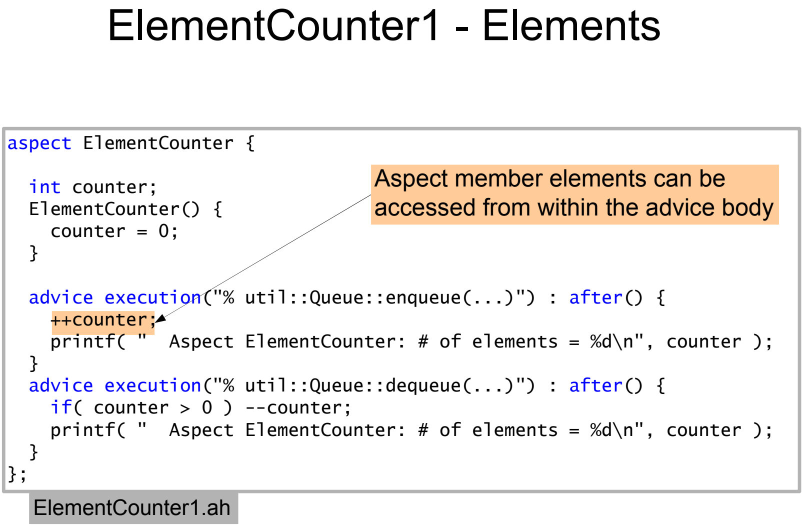
ElementCounter1 - Elements

This **pointcut expression** denotes where the advice should be given. (After **execution** of methods that match the pattern)

```
aspect ElementCounter {

  int counter;
  ElementCounter() {
    counter = 0;
  }

  advice execution("% util::Queue::enqueue(...)") : after() {
    ++counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", counter );
  }
  advice execution("% util::Queue::dequeue(...)") : after() {
    if( counter > 0 ) --counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", counter );
  }
};
```

ElementCounter1.ah

Queue: Element Counting



ElementCounter1 - Elements

```
aspect ElementCounter {

  int counter;
  ElementCounter() {
    counter = 0;
  }

  advice execution("% util::Queue::enqueue(...)") : after() {
    ++counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", counter );
  }
  advice execution("% util::Queue::dequeue(...)") : after() {
    if( counter > 0 ) --counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", counter );
  }
};
```

Aspect member elements can be accessed from within the advice body

ElementCounter1.ah

03-AspectC++_handout

Queue: Element Counting

ElementCounter1 - Result

```
int main() {
  util::Queue queue;

  printf("main(): enqueueing an item\n");
  queue.enqueue( new util::Item );

  printf("main(): dequeueing two items\n");
  Util::Item* item;
  item = queue.dequeue();
  item = queue.dequeue();
}
```

main.cc

```
main(): enqueueing am item
  > Queue::enqueue(00320FD0)
  < Queue::enqueue(00320FD0)
  Aspect ElementCounter: # of elements = 1
 main(): dequeueing two items
  > Queue::dequeue()
  < Queue::dequeue() returning 00320FD0
  Aspect ElementCounter: # of elements = 0
  > Queue::dequeue()
  < Queue::dequeue() returning 00000000
  Aspect ElementCounter: # of elements = 0
```

<Output>

Queue: Element Counting

ElementCounter1 – What's next?

- The aspect is not the ideal place to store the counter, because it is shared between all Queue instances
- Ideally, counter becomes a member of Queue
- In the next step, we
  - move counter into Queue by **introduction**
  - **expose context** about the aspect invocation to access the current Queue instance

Queue: Element Counting

ElementCounter2

```
aspect ElementCounter {

  advice "util::Queue" : slice class {
    int counter;
  public:
    int count() const { return counter; }
  };
  advice execution("% util::Queue::enqueue(...)")
                   && that(queue) : after( util::Queue& queue )  {
    ++queue.counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", queue.count() );
  }
  advice execution("% util::Queue::dequeue(...)")
                   && that(queue) : after( util::Queue& queue )  {
    if( queue.count() > 0 ) --queue.counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", queue.count() );
  }
  advice construction("util::Queue")
                   && that(queue) : before( util::Queue& queue ) {
    queue.counter = 0;
  }
};
```

ElementCounter2.ah

Queue: Element Counting

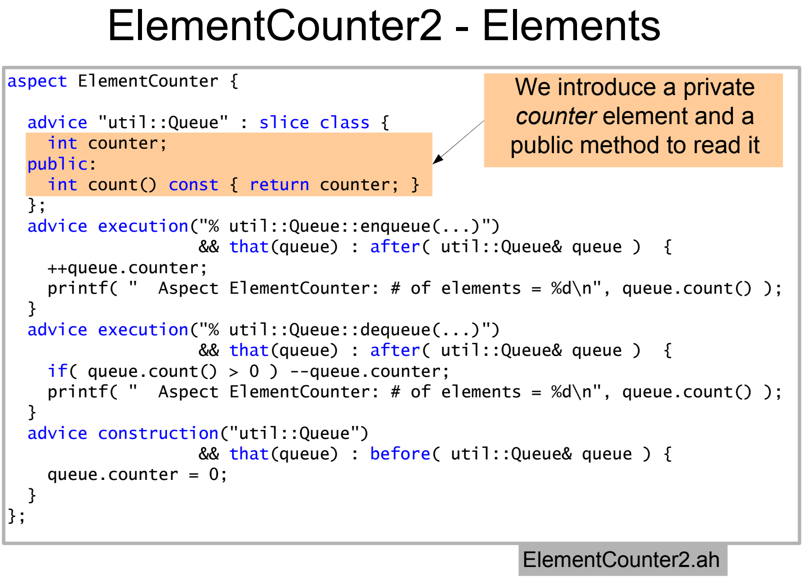
ElementCounter2 - Elements

```
aspect ElementCounter {

  advice "util::Queue" : slice class {
    int counter;
  public:
    int count() const { return counter; }
  };
  advice execution("% util::Queue::enqueue(...)")
                   && that(queue) : after( util::Queue& queue )  {
    ++queue.counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", queue.count() );
  }
  advice execution("% util::Queue::dequeue(...)")
                   && that(queue) : after( util::Queue& queue )  {
    if( queue.count() > 0 ) --queue.counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", queue.count() );
  }
  advice construction("util::Queue")
                   && that(queue) : before( util::Queue& queue ) {
    queue.counter = 0;
  }
};
```

Introduces a **slice** of members into all classes denoted by the pointcut "util::Queue"

ElementCounter2.ah

Queue: Element Counting



ElementCounter2 - Elements

```
aspect ElementCounter {

  advice "util::Queue" : slice class {
    int counter;
  public:
    int count() const { return counter; }
  };
  advice execution("% util::Queue::enqueue(...)")
                   && that(queue) : after( util::Queue& queue )  {
    ++queue.counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", queue.count() );
  }
  advice execution("% util::Queue::dequeue(...)")
                   && that(queue) : after( util::Queue& queue )  {
    if( queue.count() > 0 ) --queue.counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", queue.count() );
  }
  advice construction("util::Queue")
                   && that(queue) : before( util::Queue& queue ) {
    queue.counter = 0;
  }
};
```

We introduce a private *counter* element and a public method to read it

ElementCounter2.ah

ElementCounter2 - Elements

```
aspect ElementCounter {

  advice "util::Queue" : slice class {
    int counter;
  public:
    int count() const { return counter; }
  };
  advice execution("% util::Queue::enqueue(...)")
                   && that(queue) : after( util::Queue& queue )  {
    ++queue.counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", queue.count() );
  }
  advice execution("% util::Queue::dequeue(...)")
                   && that(queue) : after( util::Queue& queue )  {
    if( queue.count() > 0 ) --queue.counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", queue.count() );
  }
  advice construction("util::Queue")
                   && that(queue) : before( util::Queue& queue ) {
    queue.counter = 0;
  }
};
```

A **context variable** *queue* is bound to *that* (the calling instance). The calling instance has to be an util::Queue

ElementCounter2.ah

Queue: Element Counting

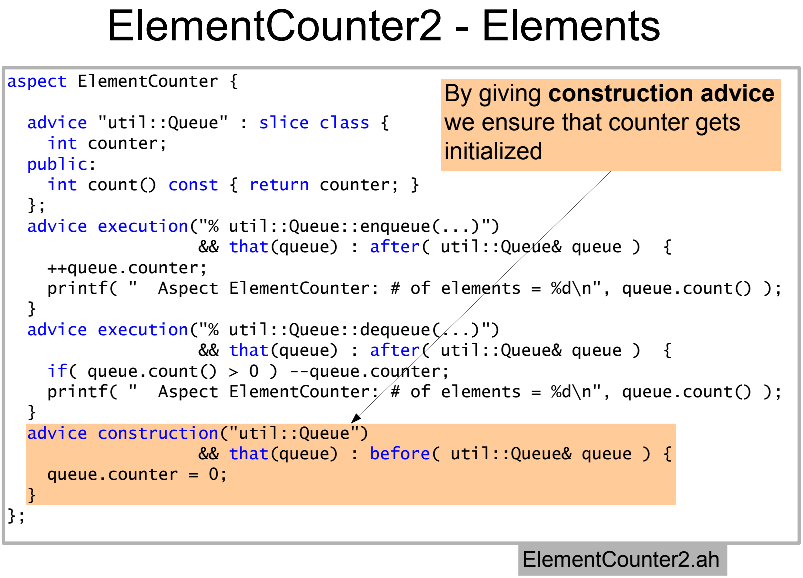
ElementCounter2 - Elements

```
aspect ElementCounter {

  advice "util::Queue" : slice class {
    int counter;
  public:
    int count() const { return counter; }
  };
  advice execution("% util::Queue::enqueue(...)")
                  && that(queue) : after( util::Queue& queue )  {
    ++queue.counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", queue.count() );
  }
  advice execution("% util::Queue::dequeue(...)")
                  && that(queue) : after( util::Queue& queue )  {
    if( queue.count() > 0 ) --queue.counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", queue.count() );
  }
  advice construction("util::Queue")
                  && that(queue) : before( util::Queue& queue ) {
    queue.counter = 0;
  }
};
```

The context variable *queue* is used to access the calling instance.

ElementCounter2.ah

Queue: Element Counting



ElementCounter2 - Elements

```
aspect ElementCounter {

  advice "util::Queue" : slice class {
    int counter;
  public:
    int count() const { return counter; }
  };
  advice execution("% util::Queue::enqueue(...)")
                   && that(queue) : after( util::Queue& queue )  {
    ++queue.counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", queue.count() );
  }
  advice execution("% util::Queue::dequeue(...)")
                   && that(queue) : after( util::Queue& queue )  {
    if( queue.count() > 0 ) --queue.counter;
    printf( "  Aspect ElementCounter: # of elements = %d\n", queue.count() );
  }
  advice construction("util::Queue")
                   && that(queue) : before( util::Queue& queue ) {
    queue.counter = 0;
  }
};
```

By giving **construction advice** we ensure that counter gets initialized

ElementCounter2.ah

Queue: Element Counting

ElementCounter2 - Result

```
int main() {
  util::Queue queue;
  printf("main(): Queue contains %d items\n", queue.count());
  printf("main(): enqueueing some items\n");
  queue.enqueue(new util::Item);
  queue.enqueue(new util::Item);
  printf("main(): Queue contains %d items\n", queue.count());
  printf("main(): dequeueing one items\n");
  util::Item* item;
  item = queue.dequeue();
  printf("main(): Queue contains %d items\n", queue.count());
}
```

main.cc

Queue: Element Counting

ElementCounter2 - Result

```
int main() {
  util::Queue queue;
  printf("main(): Queue contains %d items\n", queue.count());
  printf("main(): enqueueing some items\n");
  queue.enqueue(new util::Item);
  queue.enqueue(new util::Item);
  printf("main(): Queue contains
  printf("main(): dequeueing one
  util::Item* item;
  item = queue.dequeue();
  printf("main(): Queue contains
}
```

main.cc

```
main(): Queue contains 0 items
main(): enqueueing some items
  > Queue::enqueue(00320FD0)
  < Queue::enqueue(00320FD0)
  Aspect ElementCounter: # of elements = 1
  > Queue::enqueue(00321000)
  < Queue]::enqueue(00321000)
  Aspect ElementCounter: # of elements = 2
main(): Queue contains 2 items
main(): dequeueing one items
  > Queue::dequeue()
  < Queue::dequeue() returning 00320FD0
  Aspect ElementCounter: # of elements = 1
main(): Queue contains 1 items
```

<Output>

ElementCounter – Lessons Learned

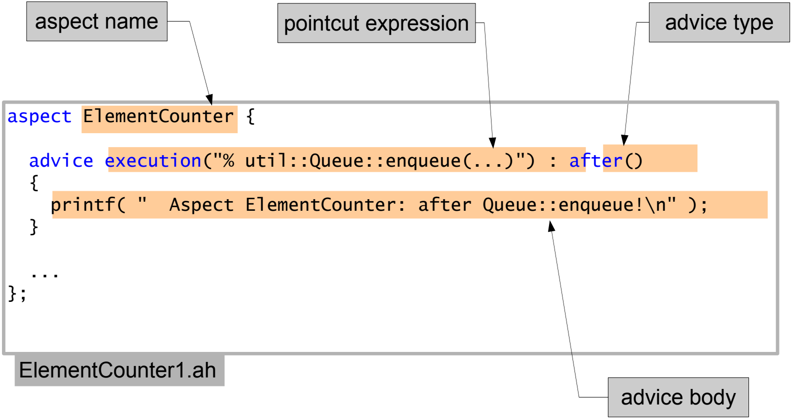
You have seen...

- the most important concepts of AspectC++
  - Aspects are introduced with the keyword *aspect*
  - They are much like a class, may contain methods, data members, types, inner classes, etc.
  - Additionaly, aspects can give *advice* to be woven in at certain positions (*joinpoints*). Advice can be given to
    - Functions/Methods/Constructors: code to execute (*code advice*)
    - Classes or structs: new elements (*introductions*)
  - Joinpoints are described by *pointcut expressions*

- We will now take a closer look at some of them

AspectC++ Language Elements

Syntactic Elements



aspect name

pointcut expression

advice type

```
aspect ElementCounter {

  advice execution("% util::Queue::enqueue(...)") : after()
  {
    printf( "  Aspect ElementCounter: after Queue::enqueue!\n" );
  }

  ...
};
```

ElementCounter1.ah

advice body

Joinpoints

- A **joinpoint** denotes a position to give advice
  - **Code** joinpoint
    a point in the **control flow** of a running program, e.g.
    - **execution** of a function
    - **call** of a function
  - **Name** joinpoint
    - a **named C++ program entity** (identifier)
    - class, function, method, type, namespace
- Joinpoints are given by **pointcut expressions**
  - a pointcut expression describes a **set of joinpoints**

Pointcut Expressions

- Pointcut expressions are made from ...
  - **match expressions**, e.g. "% util::queue::enqueue(...)"
    - are matched against C++ programm entities → name joinpoints
    - support wildcards
  - **pointcut functions**, e.g execution(...), call(...), that(...)
    - **execution:** all points in the control flow, where a function is about to be executed → code joinpoints
    - **call:** all points in the control flow, where a function is about to be called → code joinpoints
- Pointcut functions can be combined into expressions
  - using logical connectors: &&, ||, !
  - Example: call("% util::Queue::enqueue(...)") && within("% main(...)")

Advice

Advice to functions

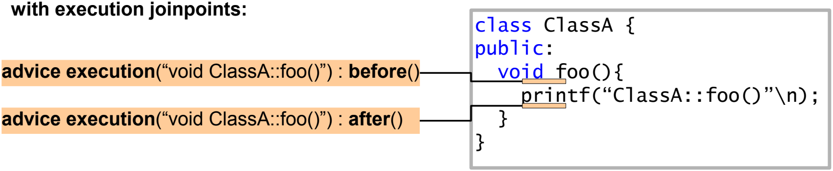
- **before advice**
  - Advice code is executed **before** the original code
  - Advice may read/modify parameter values
- **after advice**
  - Advice code is executed **after** the original code
  - Advice may read/modify return value
- **around advice**
  - Advice code is executed **instead of** the original code
  - Original code may be called explicitly: `tjp->proceed()`

Introductions

- A *slice* of additional methods, types, etc. is added to the class
- Can be used to extend the interface of a class

Before / After Advice

with execution joinpoints:

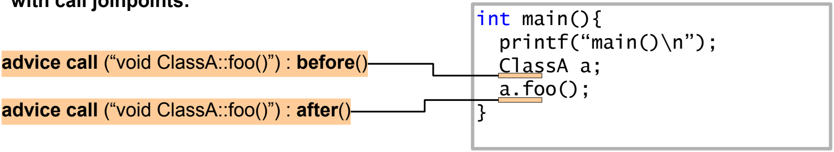


advice execution(“void ClassA::foo()”) : **before**()

advice execution(“void ClassA::foo()”) : **after**()

```
class ClassA {
public:
  void foo(){
    printf(“ClassA::foo()”\n);
  }
}
```

with call joinpoints:



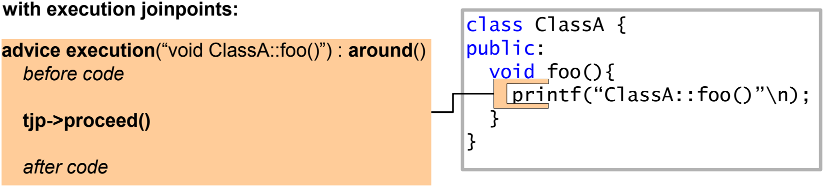
advice call (“void ClassA::foo()”) : **before**()

advice call (“void ClassA::foo()”) : **after**()

```
int main(){
  printf(“main()\n”);
  ClassA a;
  a.foo();
}
```

Around Advice

with execution joinpoints:



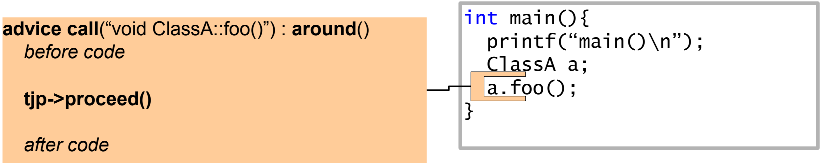
advice execution(“void ClassA::foo()”) : **around**()
before code

tjp->proceed()

after code

```
class ClassA {
public:
  void foo(){
    printf(“ClassA::foo()”\n);
  }
}
```

with call joinpoints:



advice call(“void ClassA::foo()”) : **around**()
before code

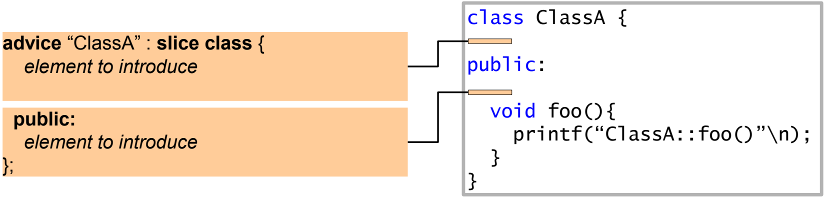
tjp->proceed()

after code

```
int main(){
  printf(“main()\n”);
  ClassA a;
  a.foo();
}
```

AspectC++ Language Elements

Introductions



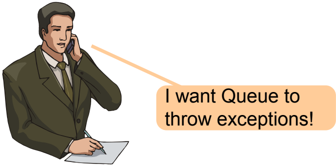
advice “ClassA” : **slice class** {
element to introduce

public:
element to introduce
};

```
class ClassA {

public:

  void foo(){
    printf(“ClassA::foo()”\n);
  }
}
```

Queue: Demanded Extensions

I. Element counting



II. Errorhandling
(signaling of errors by exceptions)

III. Thread safety
(synchronization by mutex variables)

Queue: Error Handling

Errorhandling: The Idea

- We want to check the following constraints:
  - enqueue() is never called with a NULL item
  - dequeue() is never called on an empty queue
- In case of an error an exception should be thrown

- To implement this, we need access to ...
  - the parameter passed to enqueue()
  - the return value returned by dequeue()

  ... from within the advice

Queue: Error Handling

ErrorException

```
namespace util {
  struct QueueInvalidItemError {};
  struct QueueEmptyError {};
}

aspect ErrorException {

  advice execution("% util::Queue::enqueue(...)") && args(item)
      : before(util::Item* item) {
    if( item == 0 )
      throw util::QueueInvalidItemError();
  }
  advice execution("% util::Queue::dequeue(...)") && result(item)
      : after(util::Item* item) {
    if( item == 0 )
      throw util::QueueEmptyError();
  }
};
```

ErrorException.ah

Queue: Error Handling

ErrorException - Elements

```
namespace util {
  struct QueueInvalidItemError {};
  struct QueueEmptyError {};
}

aspect ErrorException {

  advice execution("% util::Queue::enqueue(...)") && args(item)
      : before(util::Item* item) {
    if( item == 0 )
      throw util::QueueInvalidItemError();
  }
  advice execution("% util::Queue::dequeue(...)") && result(item)
      : after(util::Item* item) {
    if( item == 0 )
      throw util::QueueEmptyError();
  }
};
```

ErrorException.ah

We give advice to be executed *before* enqueue() and *after* dequeue()

Queue: Error Handling

ErrorException - Elements

```
namespace util {
  struct QueueInvalidItemEr
  struct QueueEmptyError {};
}

aspect ErrorException {

  advice execution("% util::Queue::enqueue(...)") && args(item)
      : before(util::Item* item) {
    if( item == 0 )
      throw util::QueueInvalidItemError();
  }
  advice execution("% util::Queue::dequeue(...)") && result(item)
      : after(util::Item* item) {
    if( item == 0 )
      throw util::QueueEmptyError();
  }
};
```

A **context variable** *item* is bound to the first **argument** of type *util::Item** passed to the matching methods

ErrorException.ah

Queue: Error Handling

ErrorException - Elements

```
namespace util {
  struct QueueInvalidItemEr
  struct QueueEmptyError {}
}

aspect ErrorException {

  advice execution("% util::Queue::enqueue(...)") && args(item)
      : before(util::Item* item) {
    if( item == 0 )
      throw util::QueueInvalidItemError();
  }
  advice execution("% util::Queue::dequeue(...)") && result(item)
      : after(util::Item* item) {
    if( item == 0 )
      throw util::QueueEmptyError();
  }
};
```

Here the **context variable** *item* is bound to the **result** of type *util::Item** returned by the matching methods

ErrorException.ah

ErrorException – Lessons Learned

You have see how to ...

- use different types of advice
  - **before** advice
  - **after** advice
- expose context in the advice body
  - by using **args** to read/modify parameter values
  - by using **result** to read/modify the return value

Queue: Demanded Extensions

I. Element counting

II. Errorhandling
(signaling of errors by exceptions)

III. Thread safety
(synchronization by mutex variables)

Thread Safety: The Idea

- Protect enqueue() and dequeue() by a mutex object

- To implement this, we need to
  - introduce a mutex variable into class Queue
  - lock the mutex before the execution of enqueue() / dequeue()
  - unlock the mutex after execution of enqueue() / dequeue()

- The aspect implementation should be exception safe!
  - in case of an exception, pending after advice is not called
  - solution: use around advice

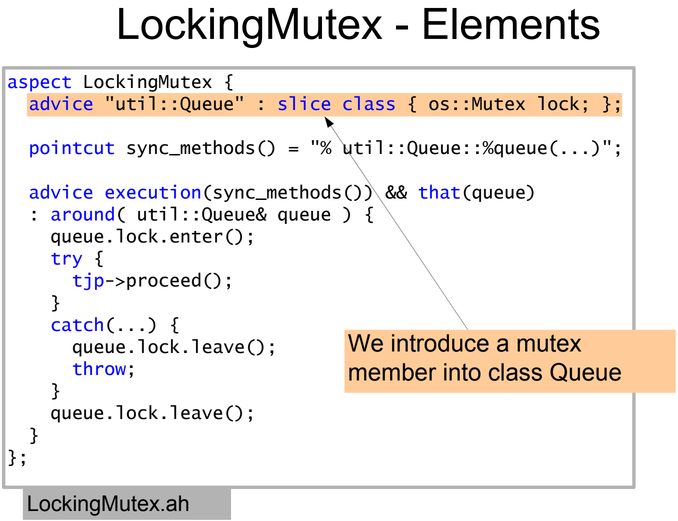
Queue: Thread Synchronization

LockingMutex

```
aspect LockingMutex {
  advice "util::Queue" : slice class { os::Mutex lock; };

  pointcut sync_methods() = "% util::Queue::%queue(...)";

  advice execution(sync_methods()) && that(queue)
  : around( util::Queue& queue ) {
    queue.lock.enter();
    try {
      tjp->proceed();
    }
    catch(...) {
      queue.lock.leave();
      throw;
    }
    queue.lock.leave();
  }
};
```

LockingMutex.ah

Queue: Thread Synchronization



LockingMutex - Elements

```
aspect LockingMutex {
  advice "util::Queue" : slice class { os::Mutex lock; };

  pointcut sync_methods() = "% util::Queue::%queue(...)";

  advice execution(sync_methods()) && that(queue)
  : around( util::Queue& queue ) {
    queue.lock.enter();
    try {
      tjp->proceed();
    }
    catch(...) {
      queue.lock.leave();
      throw;
    }
    queue.lock.leave();
  }
};
```

LockingMutex.ah

We introduce a mutex member into class Queue

Queue: Thread Synchronization

LockingMutex - Elements

```
aspect LockingMutex {
  advice "util::Queue" : slice class { os::Mutex lock; };

  pointcut sync_methods() = "% util::Queue::%queue(...)";

  advice execution(sync_methods()) && that(queue)
  : around( util::Queue& queue ) {
    queue.lock.enter();
    try {
      tjp->proceed();
    }
    catch(...) {
      queue.lock.leave();
      throw;
    }
    queue.lock.leave();
  }
};
```

LockingMutex.ah

Pointcuts can be named. *sync_methods* describes all methods that have to be synchronized by the mutex

Queue: Thread Synchronization

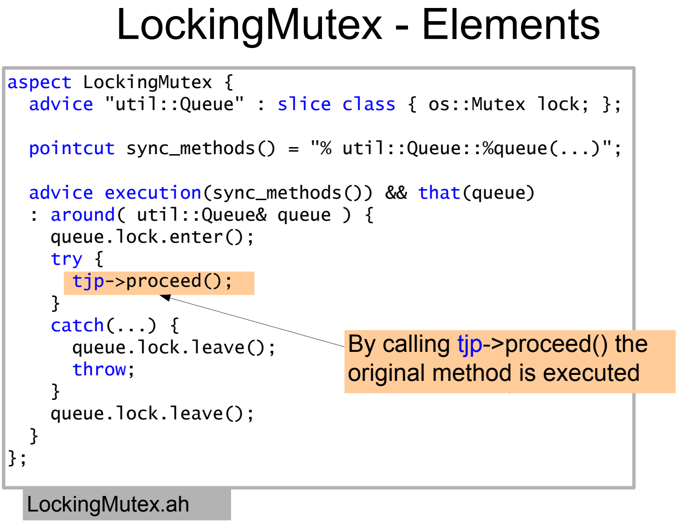
LockingMutex - Elements

```
aspect LockingMutex {
  advice "util::Queue" : slice class { os::Mutex lock; };

  pointcut sync_methods() = "% util::Queue::%queue(...)";

  advice execution(sync_methods()) && that(queue)
  : around( util::Queue& queue ) {
    queue.lock.enter();
    try {
      tjp->proceed();
    }
    catch(...) {
      queue.lock.leave();
      throw;
    }
    queue.lock.leave();
  }
};
```

LockingMutex.ah

sync_methods is used to give around advice to the execution of the methods

Queue: Thread Synchronization



LockingMutex - Elements

```
aspect LockingMutex {
  advice "util::Queue" : slice class { os::Mutex lock; };

  pointcut sync_methods() = "% util::Queue::%queue(...)";

  advice execution(sync_methods()) && that(queue)
  : around( util::Queue& queue ) {
    queue.lock.enter();
    try {
      tjp->proceed();
    }
    catch(...) {
      queue.lock.leave();
      throw;
    }
    queue.lock.leave();
  }
};
```

By calling tjp->proceed() the original method is executed

LockingMutex.ah

LockingMutex – Lessons Learned

You have seen how to ...

- use named pointcuts
  - to increase readability of pointcut expressions
  - to reuse pointcut expressions
- use around advice
  - to deal with exception safety
  - to explicit invoke (or don't invoke) the original code by calling `tjp->proceed()`
- use wildcards in match expressions
  - "% util::Queue::%queue(...)" matches both enqueue() and dequeue()

Queue: A new Requirement

I. Element counting

II. Errorhandling
(signaling of errors by exceptions)

III. Thread safety
(synchronization by mutex variables)

IV. Interrupt safety
(synchronization on interrupt level)

Interrupt Safety: The Idea

- Scenario
  - Queue is used to transport objects between kernel code (interrupt handlers) and application code
  - If application code accesses the queue, interrupts must be disabled first
  - If kernel code accesses the queue, interrupts must not be disabled
- To implement this, we need to distinguish
  - if the call is made from kernel code, or
  - if the call is made from application code

Queue: IRQ Synchronization

LockingIRQ1

```
aspect LockingIRQ {

  pointcut sync_methods() = "% util::Queue::%queue(...)";
  pointcut kernel_code()  = "% kernel::%(...)";

  advice call(sync_methods()) && !within(kernel_code()) : around() {
    os::disable_int();
    try {
      tjp->proceed();
    }
    catch(...) {
      os::enable_int();
      throw;
    }
    os::enable_int();
  }
};
```

LockingIRQ1.ah

Queue: IRQ Synchronization

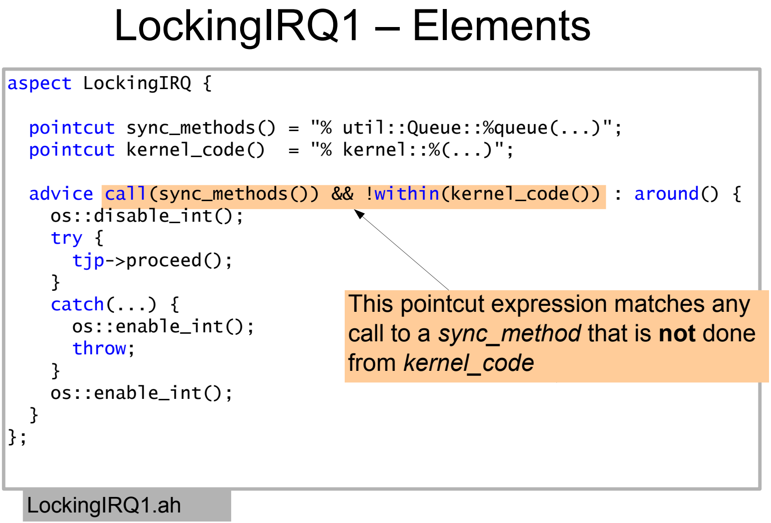
LockingIRQ1 – Elements

```
aspect LockingIRQ {

  pointcut sync_methods() = "% util::Queue::%queue(...)";
  pointcut kernel_code()  = "% kernel::%(...)";

  advice call(sync_methods()) && !within(kernel_code()) : around() {
    os::disable_int();
    try {
      tjp->proceed();
    }
    catch(...) {
      os::enable_int();
      throw;
    }
    os::enable_int();
  }
};
```

We define two pointcuts. One for the methods to be synchronized and one for all kernel functions

LockingIRQ1.ah

Queue: IRQ Synchronization



LockingIRQ1 – Elements

```
aspect LockingIRQ {

  pointcut sync_methods() = "% util::Queue::%queue(...)";
  pointcut kernel_code()  = "% kernel::%(...)";

  advice call(sync_methods()) && !within(kernel_code()) : around() {
    os::disable_int();
    try {
      tjp->proceed();
    }
    catch(...) {
      os::enable_int();
      throw;
    }
    os::enable_int();
  }
};
```

This pointcut expression matches any call to a *sync_method* that is **not** done from *kernel_code*

LockingIRQ1.ah

Queue: IRQ Synchronization

LockingIRQ1 – Result

```
util::Queue queue;
void do_something() {
  printf("do_something()\n");
  queue.enqueue( new util::Item );
}
namespace kernel {
  void irq_handler() {
    printf("kernel::irq_handler()\n")
    queue.enqueue(new util::Item);
    do_something();
  }
}
int main() {
  printf("main()\n");
  queue.enqueue(new util::Item);
  kernel::irq_handler();  // irq
  printf("back in main()\n");
  queue.dequeue();
}
```

main.cc

```
main()
os::disable_int()
  > Queue::enqueue(00320FD0)
  < Queue::enqueue()
os::enable_int()
kernel::irq_handler()
  > Queue::enqueue(00321030)
  < Queue::enqueue()
do_something()
os::disable_int()
  > Queue::enqueue(00321060)
  < Queue::enqueue()
os::enable_int()
back in main()
os::disable_int()
  > Queue::dequeue()
  < Queue::dequeue() returning 00320FD0
os::enable_int()
```

<Output>

LockingIRQ1 – Problem

```
util::Queue queue;
void do_something() {
  printf("do_something()\n");
  queue.enqueue( new util::Item );
}
namespace kernel {
  void irq_handler() {
    printf("kernel::irq_handler()\n");
    queue.enqueue(new util::Item);
    do_something();
  }
}
int main() {
  printf("main()\n");
  queue.enqueue(new util::Item);
  kernel::irq_handler();  // irq
  printf("back in main()\n");
  queue.dequeue();
}
```

main.cc

The pointcut within(*kernel_code*) does not match any **indirect** calls to *sync_methods*

```
ma
os


  < Queue::enqueue()
os::enable_int()
kernel::irq_handler()
  > Queue::enqueue(00321030)
  < Queue::enqueue()
do_something()
os::disable_int()
  > Queue::enqueue(00321060)
  < Queue::enqueue()
os::enable_int()
back in main()
os::disable_int()
  > Queue::dequeue()
  < Queue::dequeue() returning 00320FD0
os::enable_int()
```

<Output>

03-AspectC++_handout

Queue: IRQ Synchronization

LockingIRQ2

```
aspect LockingIRQ {

  pointcut sync_methods() = "% util::Queue::%queue(...)";
  pointcut kernel_code()  = "% kernel::%(...)";

  advice execution(sync_methods())
  && !cflow(execution(kernel_code())) : around() {
    os::disable_int();
    try {
      tjp->proceed();
    }
    catch(...) {
      os::enable_int();
      throw;
    }
    os::enable_int();
  }
};
```

LockingIRQ2.ah

Solution
Using the **cflow** pointcut function

Queue: IRQ Synchronization

LockingIRQ2 – Elements

```
aspect LockingIRQ {

  pointcut sync_methods() = "% util::Queue::%queue(...)";
  pointcut kernel_code()  = "% kernel::%(...)";

  advice execution(sync_methods())
  && !cflow(execution(kernel_code())) : around() {
    os::disable_int();
    try {
      tjp->proceed();
    }
    catch(...) {
      os::enable_int();
      throw;
    }
    os::enable_int();
  }
};
```

LockingIRQ2.ah

This pointcut expression matches the execution of *sync_methods* if no *kernel_code* is on the call stack. cflow checks the call stack (control flow) at runtime.

LockingIRQ2 – Result

```
util::Queue queue;
void do_something() {
  printf("do_something()\n");
  queue.enqueue( new util::Item );
}
namespace kernel {
  void irq_handler() {
    printf("kernel::irq_handler()\n")
    queue.enqueue(new util::Item);
    do_something();
  }
}
int main() {
  printf("main()\n");
  queue.enqueue(new util::Item);
  kernel::irq_handler();  // irq
  printf("back in main()\n");
  queue.dequeue();
}
```

main.cc

```
main()
os::disable_int()
  > Queue::enqueue(00320FD0)
  < Queue::enqueue()
os::enable_int()
kernel::irq_handler()
  > Queue::enqueue(00321030)
  < Queue::enqueue()
do_something()
  > Queue::enqueue(00321060)
  < Queue::enqueue()
back in main()
os::disable_int()
  > Queue::dequeue()
  < Queue::dequeue() returning 00320FD0
os::enable_int()
```

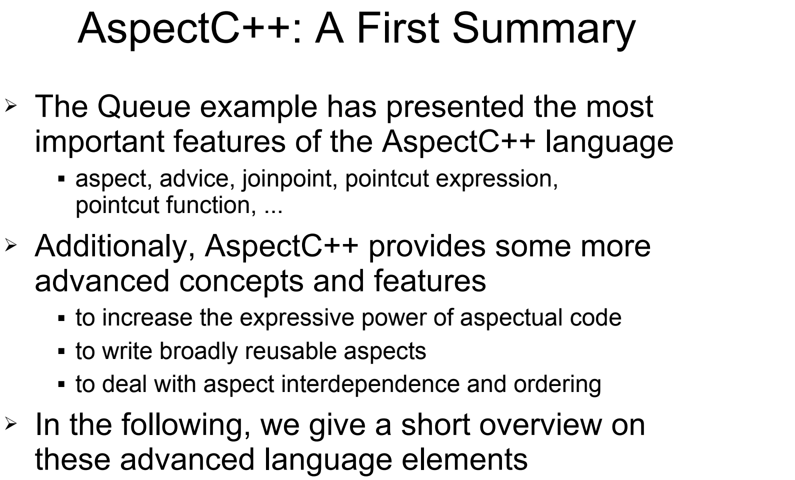
<Output>

LockingIRQ – Lessons Learned

You have seen how to ...

- restrict advice invocation to a specific calling context
- use the within(...) and cflow(...) pointcut functions
  - **within** is evaluated at **compile time** and returns all code joinpoints of a class' or namespaces lexical scope
  - **cflow** is evaluated at **runtime** and returns all joinpoints where the control flow is below a specific code joinpoint

A First Summary



AspectC++: A First Summary

- The Queue example has presented the most important features of the AspectC++ language
  - aspect, advice, joinpoint, pointcut expression, pointcut function, ...
- Additionaly, AspectC++ provides some more advanced concepts and features
  - to increase the expressive power of aspectual code
  - to write broadly reusable aspects
  - to deal with aspect interdependence and ordering
- In the following, we give a short overview on these advanced language elements

Agenda

3.1 Motivation: Separation of Concerns

3.2 Tutorial: AspectC++

- Example Szenario
- First Steps And Language Overview
- Advanced Concepts
- Weaver Transformations
- Further Examples

3.3 Summary and Outlook

3.4 References

AspectC++: Advanced Concepts

- Join Point API
  - provides a uniform interface to the aspect invocation context, both at runtime and compile-time
- Abstract Aspects and Aspect Inheritance
  - comparable to class inheritance, aspect inheritance allows to reuse parts of an aspect and overwrite other parts
- Generic Advice
  - exploits static type information in advice code
- Aspect Ordering
  - allows to specify the invocation order of multiple aspects
- Aspect Instantiation
  - allows to implement user-defined aspect instantiation models

The Joinpoint API

- Inside an advice body, the current joinpoint context is available via the **implicitly passed tjp** variable:

```
advice ... {
  struct JoinPoint {
    ...
  } *tjp;      // implicitly available in advice code
  ...
}
```

- You have already seen how to use tjp, to ...
  - execute the original code in around advice with **tjp->proceed()**
- The joinpoint API provides a rich interface
  - to expose context **independently** of the aspect target
  - this is especially useful in writing **reusable aspect code**

The Join Point API (Excerpt)

Types (compile-time)

```
 // object type (initiator)
That
// object type (receiver)
Target
// result type of the affected function
Result
// type of the i'th argument of the affected
// function (with 0 <= i < ARGS)
Arg<i>::Type
Arg<i>::ReferredType
```

Consts (compile-time)

```
// number of arguments
ARGS
// unique numeric identifier for this join point
JPID
// numeric identifier for the type of this join
// point (AC::CALL, AC::EXECUTION, ...)
JPTYPE
```

Values (runtime)

```
// pointer to the object initiating a call
That* that()
// pointer to the object that is target of a call
Target* target()
// pointer to the result value
Result* result()
// typed pointer the i'th argument value of a
// function call (compile-time index)
Arg<i>::ReferredType* arg()
// pointer the i'th argument value of a
// function call (runtime index)
void* arg( int i )
// textual representation of the joinpoint
// (function/class name, parameter types...)
static const char* signature()
// executes the original joinpoint code
// in an around advice
void proceed()
// returns the runtime action object
AC::Action& action()
```

Abstract Aspects and Inheritance

- Aspects can inherit from other aspects...
  - Reuse aspect definitions
  - Override methods and pointcuts
- Pointcuts can be pure virtual
  - Postpone the concrete definition to derived aspects
  - An aspect with a pure virtual pointcut is called **abstract aspect**
- Common usage: Reusable aspect implementations
  - Abstract aspect defines advice code, but pure virtual pointcuts
  - Aspect code uses the joinpoint API to expose context
  - Concrete aspect inherits the advice code and overrides pointcuts

Abstract Aspects and Inheritance

```
#include "mutex.h"
aspect LockingA {
  pointcut virtual sync_classes() = 0;
  pointcut virtual sync_methods() = 0;

  advice sync_classes() : slice class {
    os::Mutex lock;
  };
  advice execution(sync_methods()) : around() {
    tjp->that()->lock.enter();
    try {
      tjp->proceed();
    }
    catch(...) {
      tjp->that()->lock.leave();
      throw;
    }
    tjp->that()->lock.leave();
  }
};
```

LockingA.ah

The abstract locking aspect declares two **pure virtual pointcuts** and uses the **joinpoint API** for an context-independent advice implementation.

```
#include "LockingA.ah"

aspect LockingQueue : public LockingA {
  pointcut sync_classes() =
    "util::Queue";
  pointcut sync_methods() =
    "% util::Queue::%queue(...)";
};
```

LockingQueue.ah

Abstract Aspects and Inheritance

```
#include "mutex.h"
aspect LockingA {
  pointcut virtual sync_classes() = 0;
  pointcut virtual sync_methods() = 0;

  advice sync_classes() : slice class {
    os::Mutex lock;
  };
  advice execution(sync_methods()) : around() {
    tjp->that()->lock.enter();
    try {
      tjp->proceed();
    }
    catch(...) {
      tjp->that()->lock.leave();
      throw;
    }
    tjp->that()->lock.leave();
  }
};
```

LockingA.ah

The concrete locking aspect **derives** from the abstract aspect and **overrides** the pointcuts.

```
#include "LockingA.ah"

aspect LockingQueue : public LockingA {
  pointcut sync_classes() =
    "util::Queue";
  pointcut sync_methods() =
    "% util::Queue::%queue(...)";
};
```

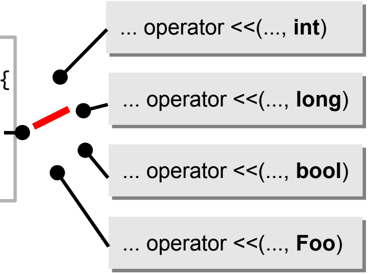
LockingQueue.ah

Generic Advice

Uses static JP-specific type information in advice code

- in combination with C++ overloading
- to instantiate C++ templates and template meta-programs

```
aspect TraceService {
  advice call(...) : after() {
    ...
    cout << *tjp->result();
  }
};
```



... operator <<(..., **int**)

... operator <<(..., **long**)

... operator <<(..., **bool**)

... operator <<(..., **Foo**)

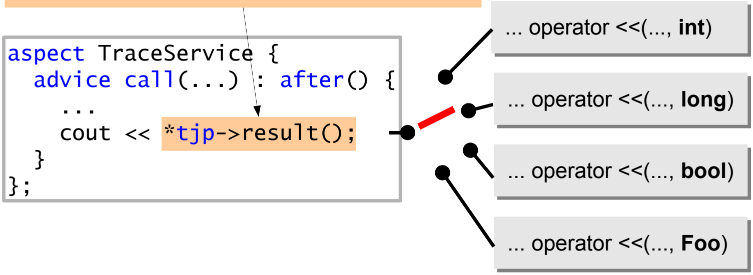
Generic Advice

Uses static JP-specific type information in advice code

- in combination with C++ overloading
- nplate meta-programs

Resolves to the **statically typed** return value

- no runtime type checks are needed
- unhandled types are detected at compile-time
- functions can be inlined



```
aspect TraceService {
  advice call(...) : after() {
    ...
    cout << *tjp->result();
  }
};
```

... operator <<(..., **int**)
... operator <<(..., **long**)
... operator <<(..., **bool**)
... operator <<(..., **Foo**)

Aspect Ordering

- Aspects should be independent of other aspects
  - However, sometimes inter-aspect dependencies are unavoidable
  - Example: Locking should be activated before any other aspects
- Order advice
  - The aspect order can be defined by ***order advice***
    advice *pointcut-expr* : order(*high, ..., low*)
  - Different aspect orders can be defined for different pointcuts
- Example

```
advice "% util::Queue::%queue(...)"
     : order( "LockingIRQ", "%" && !"LockingIRQ" );
```

Aspect Instantiation

- Aspects are singletons by default
  - **aspectof()** returns pointer to the one-and-only aspect instance
- By overriding aspectof() this can be changed
  - e.g. one instance per client or one instance per thread

```
aspect MyAspect {
  // ....
  static MyAspect* aspectof() {
    static __declspec(thread) MyAspect* theAspect;
        if( theAspect == 0 )
          theAspect = new MyAspect;
    return theAspect;
  }
};
```

MyAspect.ah

Example of an user-defined aspectof() implementation for per-thread aspect instantiation by using thread-local storage.

(Visual C++)

Agenda

3.1 Motivation: Separation of Concerns

3.2 Tutorial: AspectC++

- Example Szenario
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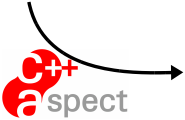
3.3 Summary and Outlook

3.4 References

Aspect Transformation

```
aspect Transform {
  advice call("% foo()") : before() {
    printf("before foo call\n");
  }
  advice execution("% C::%()") : after()
{
    printf(tjp->signature ());
  }
};
```

Transform.ah

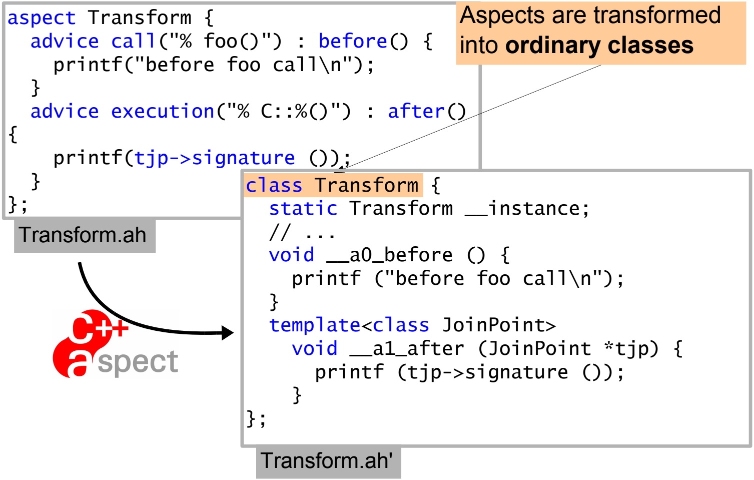


```
class Transform {
  static Transform __instance;
  // ...
  void __a0_before () {
    printf ("before foo call\n");
  }
  template<class JoinPoint>
    void __a1_after (JoinPoint *tjp) {
      printf (tjp->signature ());
    }
};
```

Transform.ah'

Weaver Transformations

Aspect Transformation



```
aspect Transform {
  advice call("% foo()") : before() {
    printf("before foo call\n");
  }
  advice execution("% C::%()") : after()
{
    printf(tjp->signature ());
  }
};
```

Transform.ah

Aspects are transformed into **ordinary classes**

```
class Transform {
  static Transform __instance;
  // ...
  void __a0_before () {
    printf ("before foo call\n");
  }
  template<class JoinPoint>
    void __a1_after (JoinPoint *tjp) {
      printf (tjp->signature ());
    }
};
```

Transform.ah'

Aspect Transformation

```
aspect Transform {
  advice call("% foo()") : before() {
    printf("before foo call\n");
  }
  advice execution("% C::%()") : after()
{
    printf(tjp->signature ());
  }
};
```

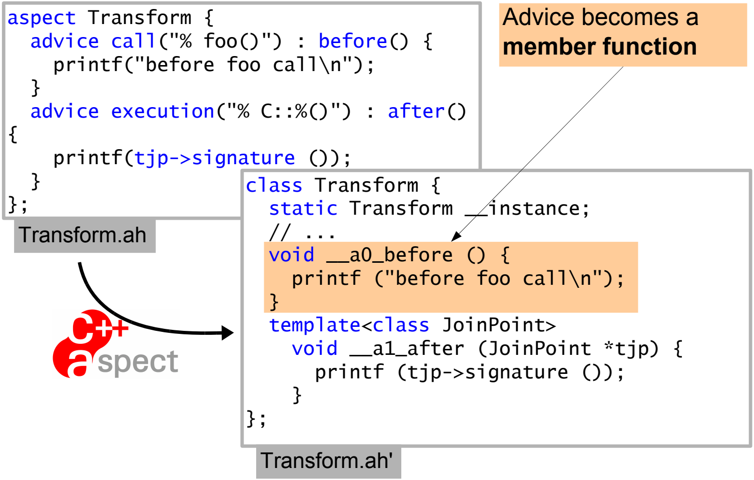
Transform.ah

One global aspect **instance** is created by default

```
class Transform {
  static Transform __instance;
  // ...
  void __a0_before () {
    printf ("before foo call\n");
  }
  template<class JoinPoint>
    void __a1_after (JoinPoint *tjp) {
      printf (tjp->signature ());
    }
};
```

Transform.ah'

Aspect Transformation



```
aspect Transform {
  advice call("% foo()") : before() {
    printf("before foo call\n");
  }
  advice execution("% C::%()") : after()
{
    printf(tjp->signature ());
  }
};
```

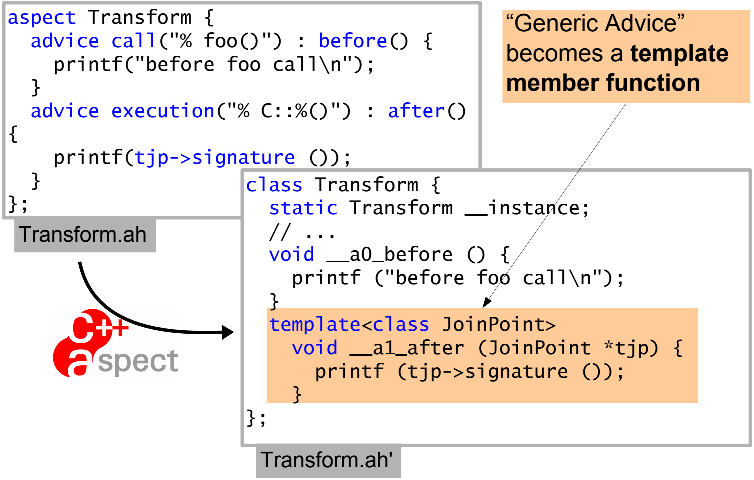
Transform.ah

Advice becomes a **member function**

```
class Transform {
  static Transform __instance;
  // ...
  void __a0_before () {
    printf ("before foo call\n");
  }
  template<class JoinPoint>
    void __a1_after (JoinPoint *tjp) {
      printf (tjp->signature ());
    }
};
```

Transform.ah'

Aspect Transformation



```
aspect Transform {
  advice call("% foo()") : before() {
    printf("before foo call\n");
  }
  advice execution("% C::%()") : after()
{
    printf(tjp->signature ());
  }
};
```

Transform.ah

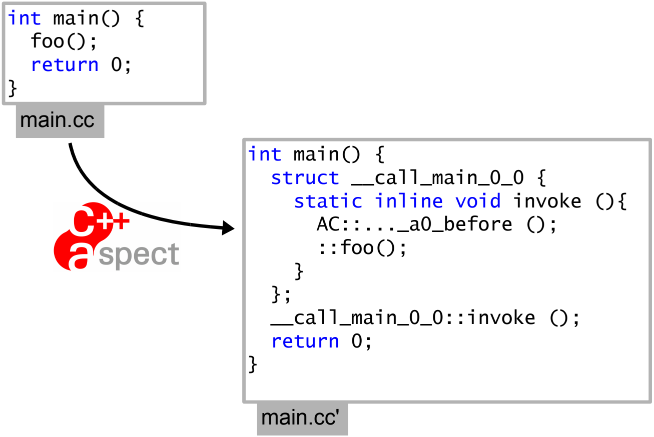
“Generic Advice” becomes a **template member function**

```
class Transform {
  static Transform __instance;
  // ...
  void __a0_before () {
    printf ("before foo call\n");
  }
  template<class JoinPoint>
    void __a1_after (JoinPoint *tjp) {
      printf (tjp->signature ());
    }
};
```

Transform.ah'

Weaver Transformations

Joinpoint Transformation



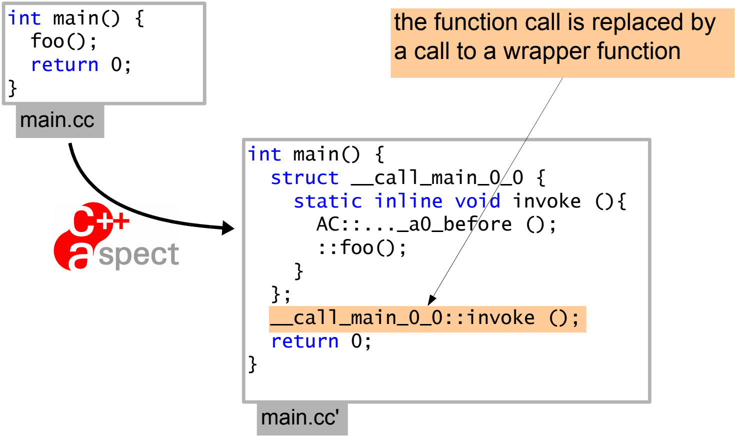
```
int main() {
  foo();
  return 0;
}
```

main.cc

```
int main() {
  struct __call_main_0_0 {
    static inline void invoke (){
      AC::..._a0_before ();
      ::foo();
    }
  };
  __call_main_0_0::invoke ();
  return 0;
}
```

main.cc'

Joinpoint Transformation



```
int main() {
  foo();
  return 0;
}
```

main.cc

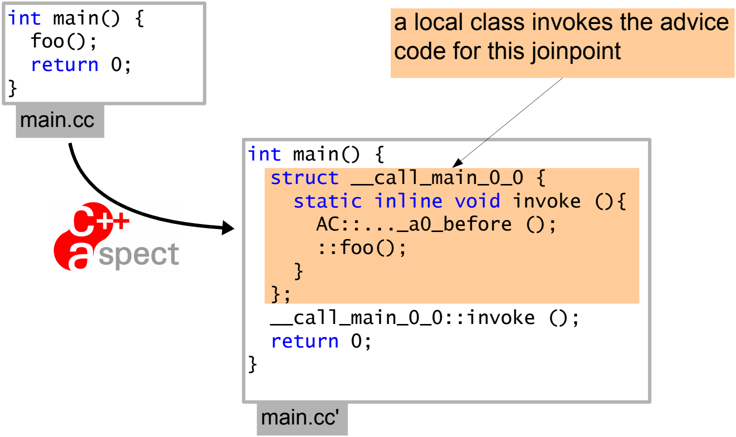
the function call is replaced by a call to a wrapper function

```
int main() {
  struct __call_main_0_0 {
    static inline void invoke (){
      AC::..._a0_before ();
      ::foo();
    }
  };
  __call_main_0_0::invoke ();
  return 0;
}
```

main.cc'

Weaver Transformations

Joinpoint Transformation



```
int main() {
  foo();
  return 0;
}
```

main.cc

a local class invokes the advice code for this joinpoint

```
int main() {
  struct __call_main_0_0 {
    static inline void invoke (){
      AC::..._a0_before ();
      ::foo();
    }
  };
  __call_main_0_0::invoke ();
  return 0;
}
```

main.cc'

Translation Modes

- Whole Program Transformation-Mode
  - e.g. `ac++ -p src -d gen -e cpp -Iinc -DDEBUG`
  - transforms whole directory trees
  - generates manipulated headers, e.g. for libraries
  - can be chained with other whole program transformation tools
- Single Translation Unit-Mode
  - e.g. `ac++ -c a.cc -o a-gen.cc -p .`
  - easier integration into build processes

Agenda

3.1 Motivation: Separation of Concerns

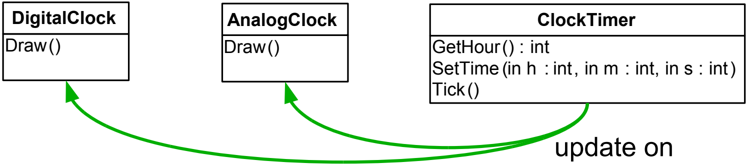
3.2 Tutorial: AspectC++

- Example Szenario
- First Steps And Language Overview
- Advanced Concepts
- Weaver Transformations
- Further Examples

3.3 Summary and Outlook

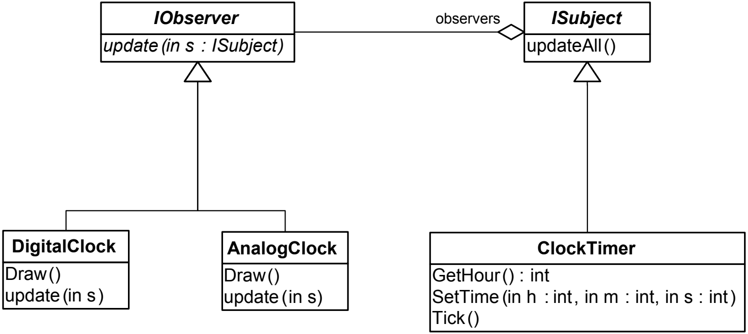
3.4 References

Observer Pattern: Scenario



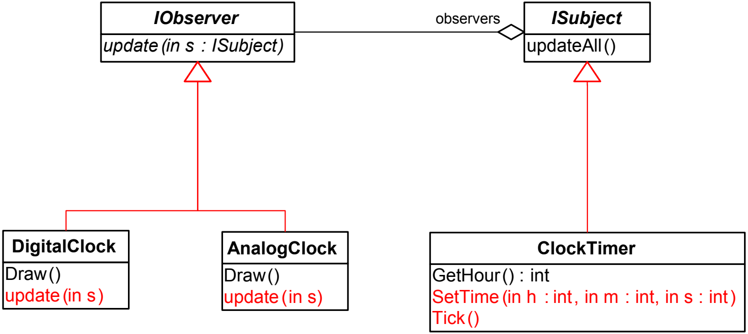
update on change

Observer Pattern: Implementation



Observer Pattern: Problem

The 'Observer Protocol' Concern...



...crosscuts the module structure

Solution: Generic Observer Aspect

```
aspect ObserverPattern {
  ...
public:
  struct ISubject {};
  struct IObserver {
    virtual void update (ISubject *) = 0;
  };

  pointcut virtual observers() = 0;
  pointcut virtual subjects() = 0;

  pointcut virtual subjectChange() =  execution( "% ...::%(...)"
                   && !"% ...::%(...) const" ) && within( subjects() );

  advice observers () : slice class : public ObserverPattern::IObserver;
  advice subjects()   : slice class : public ObserverPattern::ISubject;

  advice subjectChange() : after () {
    ISubject* subject = tjp->that();
    updateObservers( subject );
  }

  void updateObservers( ISubject* subject ) { ... }
  void addObserver( ISubject* subject, IObserver* observer ) { ... }
  void remObserver( ISubject* subject, IObserver* observer ) { ... }
};
```

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Interfaces for the subject/observer roles

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};
```

abstract pointcuts that define subjects/observers

(need to be overridden by a derived aspect)

Solution: Generic Observer Aspect

virtual pointcut defining all state-changing methods.

(Defaults to the execution of any non-const method in subjects)

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```

Introduction of the role interface as additional **baseclass** into subjects / observers

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};
```

After advice to update observers after execution of a state-changing method

Solution: Putting Everything Together

Applying the Generic Observer Aspect to the clock example

```
aspect ClockObserver : public ObserverPattern {
  // define the participants
  pointcut subjects()   = "ClockTimer";
  pointcut observers()  = "DigitalClock"||"AnalogClock";
public:
  // define what to do in case of a notification
  advice observers() : slice class {
  public:
    void update( ObserverPattern::ISubject* s ) {
      Draw();
    }
  };
};
```

Errorhandling in Legacy Code: Scenario

```
LRESULT WINAPI WndProc( HWND hWnd, UINT nMsg, WPARAM wParam, LPARAM lParam ) {
  HDC dc = NULL; PAINTSTRUCT ps = {0};

  switch( nMsg ) {
    case WM_PAINT:
      dc = BeginPaint( hWnd, &ps );
      ...
      EndPaint(hWnd, &ps);
      break;
    ...
}}

int WINAPI WinMain( ... ) {
  HANDLE hConfigFile = CreateFile( "example.config", GENERIC_READ, ... );

  WNDCLASS wc = {0, WndProc, 0, 0, ... , "Example_Class"};
  RegisterClass( &wc );
  HWND hwndMain = CreateWindowEx( 0, "Example_Class", "Example", ... );
  UpdateWindow( hwndMain );

  MSG msg;
  while( GetMessage( &msg, NULL, 0, 0 ) ) {
    TranslateMessage( &msg );
    DispatchMessage( &msg );
  }
  return 0;
}
```

A typical Win32 application

Errorhandling in Legacy Code: Scenario

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LRESULT WINAPI WndProc( HWND hWnd, UINT nMsg, WPARAM wParam, LPARAM lParam ) {
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  RegisterClass( &wc );
  HWND hwndMain = CreateWindowEx( 0, "Example_Class", "Example", ... );
  UpdateWindow( hwndMain );

  MSG msg;
  while( GetMessage( &msg, NULL, 0, 0 ) ) {
    TranslateMessage( &msg );
    DispatchMessage( &msg );
  }
  return 0;
}
```

These Win32 API functions may fail!

Win32 Errorhandling: Goals

- Detect failed calls of Win32 API functions
  - by giving after advice for any call to a Win32 function
- Throw a *helpful* exception in case of a failure
  - describing the exact circumstances and reason of the failure

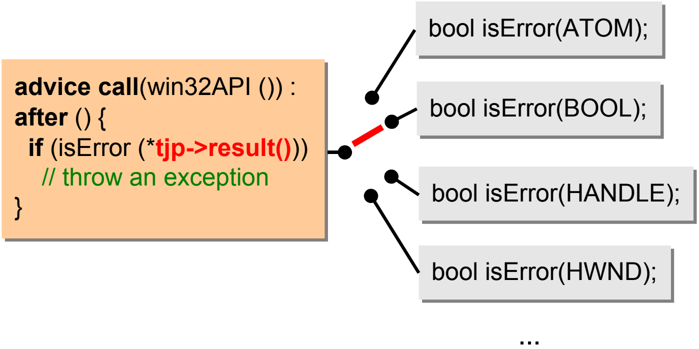
Problem: Win32 failures are indicated by a “magic” return value

- magic value to compare against depends on the ***return type*** of the function
- error reason (`GetLastError()`) only valid in case of a failure

return type	**magic value**
BOOL	FALSE
ATOM	(ATOM) 0
HANDLE	INVALID_HANDLE_VALUE or NULL
HWND	NULL

Further Examples

Detecting the failure: Generic Advice



```
advice call(win32API ()) :
after () {
  if (isError (*tjp->result()))
    // throw an exception
}
```

bool isError(ATOM);

bool isError(BOOL);

bool isError(HANDLE);

bool isError(HWND);

...

Describing the failure: Generative Advice

```
template <int I> struct ArgPrinter {
  template <class JP> static void work (JP &tjp, ostream &s) {
    ArgPrinter<I–1>::work (tjp, s);
    s << “, “ << *tjp. template arg<I-1>();
  }
};
```

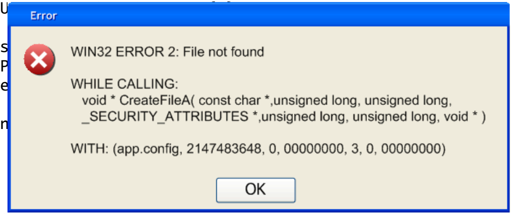
```
advice call(win32API ()) : after () {
  // throw an exception
  ostringstream s;
  DWORD code = GetLastError();
  s << “WIN32 ERROR ” << code << ...
     << win32::GetErrorText( code ) << ... <<
     << tjp->signature() << “WITH: ” << ...;
     ArgPrinter<JoinPoint::ARGS>::work (*tjp, s);

  throw win32::Exception( s.str() );
}
```

Reporting the Error

```
LRESULT WINAPI WndProc( HWND hWnd, UINT nMsg, WPARAM wParam, LPARAM lParam ) {
  HDC dc = NU

  switch( nMs
    case WM_P
      dc = Be
      ...
      EndPain
      break;
    ...
}}
```



Error

WIN32 ERROR 2: File not found

WHILE CALLING:
void * CreateFileA(const char *,unsigned long, unsigned long,
_SECURITY_ATTRIBUTES *,unsigned long, unsigned long, void *)

WITH: (app.config, 2147483648, 0, 00000000, 3, 0, 00000000)

```
int WINAPI WinMain( ... ) {
  HANDLE hConfigFile = CreateFile( "example.config", GENERIC_READ, ... );

  WNDCLASS wc = {0, WndProc, 0, 0, ... , "Example_Class"};
  RegisterClass( &wc );
  HWND hwndMain = CreateWindowEx( 0, "Example_Class", "Example", ... );
  UpdateWindow( hwndMain );

  MSG msg;
  while( GetMessage( &msg, NULL, 0, 0 ) ) {
    TranslateMessage( &msg );
    DispatchMessage( &msg );
  }
  return 0;
}
```

Agenda

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Aspect-Oriented Programming: Summary

- AOP aims at a better separation of crosscutting concerns
  - Avoidance of code tangling
    ↦ implementation of optional features
  - Avoidance of code scattering
    ↦ implementation of nonfunctional features
- Basic idea: separation of **what** from **where**
  - **Join Points** ↦ **where**
    - positions in the static structure or dynamic control flow (event)
    - given declaratively by pointcut expressions
  - **Advice** ↦ **what**
    - additional elements (members, ...) to introduce at join points
    - additional behavior (code) to superimpose at join points
- AspectC++ brings AOP concepts to the C++ world
  - Static source-to-source transformation approach

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Next Lecture:
How to use AOP to achieve loose coupling, granularity and variability for feature implementations in configurable system software
⇝ **aspect-aware design**

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[1] The British Standards Institute. *The C++ Standard (Incorporating Technical Corrigendum No. 1)*. second. Printed version of the ISO/IEC 14882:2003 standard. John Wiley & Sons, Inc., 2003. ISBN: 0-470-84674-7.

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[4] Daniel Lohmann, Fabian Scheler, Reinhard Tartler, et al. "A Quantitative Analysis of Aspects in the eCos Kernel". In: *Proceedings of the ACM SIGOPS/EuroSys European Conference on Computer Systems 2006 (EuroSys '06)*. (Leuven, Belgium). Ed. by Yolande Berbers and Willy Zwaenepoel. New York, NY, USA: ACM Press, Apr. 2006, pp. 191–204. ISBN: 1-59593-322-0. DOI: `10.1145/1218063.1217954`.

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