Thread Abstraction Layer — TAL

In Memoriam of PURE ($*$1995 †2002)

Wolfgang Schröder-Preikschat

Friedrich-Alexander University Erlangen-Nuremberg
Department of Computer Science 4
(Distributed Systems and Operating Systems)

www4.cs.fau.de

Logical Unit Construction Set Experiment
LUCSE $\mapsto$ LUXE

PURE *de Luxe*

- operating-system engineering in the small: carried to an extreme
  - playing with capabilities of C/C++ programming systems
- "pluckiness for sacrilege": an operating system is no end in itself
  - a *thread*: that's no concern of an operating system — almost...
- to apply Occam's razor:
  - *"Entia non sunt multiplicanda praeter necessitatem."*
  - *"Entities should not be multiplied beyond necessity."*

    ⋮
  - *"All other things being equal, the simplest solution is the best."*
- smooth transition: programming-language $\leftrightarrow$ operating-system level

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Specialization without Abandonment of Reusability

Cornerstones of the PURE/CiAO Development Process

PURE

family-based design eases extension and contraction of software

- stepwise *functional enrichment* of system abstractions

feature-based conditioning ensures an application-aware finishing

- mapping of features to entities of the software generation process

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CiAO

feature modeling distinguishes common from variable system properties

- identifying commonalities, differences, constraints, and conflicts

aspect-oriented programming improves separation of concerns

- factorization of cross-cutting concerns by *aspect classes*

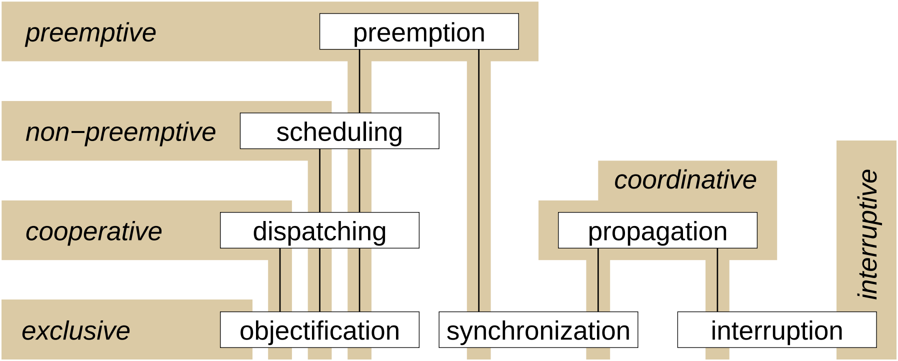
Specialization without Abandonment of Reusability (cont.)

Principles of PURE/CiAO Operating-System Engineering

minimal subset of system functions	$\Longleftrightarrow$	superclass	asset
$\downarrow$		$\downarrow$	$\downarrow$
functional enrichment		*inheritance*	*conditioning*
$\downarrow$		$\downarrow$	$\downarrow$
minimal system extensions	$\Longleftrightarrow$	subclass	specialization
program family		**OOP**	**AOP**

Family-Based Design

Minimal System Extensions to a Minimal Subset of System Functions



Operating-System Product Line

Scalable Solution in Terms of Memory Footprint and Execution Time (IA-32)

nucleus instance	size (in bytes)				latency (in cycles)
	text	*data*	*bss*	total	
exclusive	434	0	0	434	0
interruptive	812	64	392	1268	42
cooperative	1620	0	28	1648	49
non-preemptive	1671	0	28	1699	57
coordinative	1882	8	416	2306	[126, 242]
preemptive	3642	8	428	4062	300

specialized nuclei an ensemble of different operating modes

- configuration depends on user-required system properties
  - in a functional *and* non-functional sense
- application programs get what they want—no more and no less

Functional Hierarchy of Thread Abstractions

Layered According to Weight Classes

lightweight thread

↓

featherweight thread

↓

bantamweight thread

↓

flyweight thread

↓

strawweight thread

Minimal Subset of System Functions

Strawweight Thread — Use Case

```
#include "luxe/Act.h"

#define STACKSIZE 64
#define LEEWAY 16

int main (int argc, char *argv[]) {
    static Act *son, *dad;                      // thread pointers

    char pool[STACKSIZE];                       // spawner provides spawnee stack
    son = new(pool, STACKSIZE - LEEWAY) Act;    // spawner makes spawnee instance

    if ((dad = son->assume())) {                // spawner clones, spawnee erupts
        for (;;) {                              // spawnee shares state
            something();                        // spawnee does its job
            dad = dad->resume();                // spawnee yields spawner
        }
    }
    son = son->resume();                        // spawner yields spawnee
    anything();                                 // spawner does some other job
}
```

Minimal Subset of System Functions (cont.)

Strawweight Thread — Abstract Data Type

```
#include "luxe/type/size_t.h"
#include "luxe/machine/pc_t.h"

class Act {
protected:
    pc_t tbc;         // where to be continued upon resume
public:
    void* operator new (size_t, char*, size_t);
                      // return aligned (stack) pointer as "this"

    Act* assume ();   // create thread: returns twice (0 spawner, else spawnee)
    Act* resume ();   // switch thread
};
```

fundamental threading functions

- thread creation and activation “in passing”
- sharing of the entire processor state, except stack pointer
- supports control-flow switches of different thread weight classes

Minimal Subset of System Functions (cont.)

Strawweight Thread — Implementation for IA-32

```
#include "luxe/Act.h"

Act* Act::assume () {
    asm ("movl 4(%esp), %eax");              // read stack pointer of spawnee
    asm ("movl (%esp), %edx");               // grab return address of spawner
    asm ("movl %edx, (%eax)");               // pass as start address to spawnee
    return 0;                                // indicate return from spawner
}

Act* Act::resume () {
    register Act* aux;
    asm ("movl %%esp, %0" : "=r" (aux));     // remember stack pointer
    asm ("movl 4(%esp), %esp");              // switch stack
    return aux;                              // resume thread, return forerunner
}
```

idea (use `-fomit-frame-pointer`, never inline)

- hand return address down to some inactive flow of control
- provide a function whose sole task is to exchange the stack pointer

Minimal System Extensions

Thread Weight Classes and Abstraction of Different Weightily Threads

```
#include "luxe/machine/ActMode.h"

enum FluxVariety {
//  Strawweight   = Act,
    Flyweight     = GPR|OVR|OFP,  // save all except volatile and FPU registers
    Bantamweight  = GPR|OVR,      // save all except volatile registers
    Featherweight = GPR|BMR,      // save all using block move, if applicable
    Lightweight   = GPR           // save all
};
```

```
#include "luxe/Act.h"
#include "luxe/machine/FluxVariety.h"

template<FluxVariety T>
class Flux : public Act {
public:
    Act* induce (Flux<T>*&);      // create thread and inherit processor state
    Act* unwind (Act&);           // switch thread, performed inline
    Act* resume (Act&);           // switch thread: maps to unwind()
};
```

Minimal System Extensions (cont.)

Generic Thread Instantiation: "On the Fly" Inheritance of the Processor State

```
#include "luxe/Flux.h"
#include "luxe/machine/ActState.h"

template<FluxVariety T>
inline Act* Flux<T>::induce (Flux<T>*& scion) {
    Act* clade;                         // spawner thread pointer

    if ((clade = assume()))             // spawner clones, spawnee erupts
        return resume(*clade);          // spawnee adopts state, yields spawner

    scion = (Flux<T>*)Act::resume();    // spawner yields spawnee
    return 0;                           // spawner indicates its return
}
```

idea

- give new flow of control the chance to inherit some processor state
- save ones processor state before giving control back to creator

Minimal System Extensions (cont.)

Generic Thread Switching: Self-Contained Save and Restore of the Processor State

```
#include "luxe/Flux.h"
#include "luxe/machine/ActState.h"

template<FluxVariety T>
inline Act* Flux<T>::unwind (Act& next) {
    Act* peer;
    if (T & SOS) {            // save processor state onto runtime stack...
        ActState<T|BMR> *apr;             // pointer to saved processor state
        apr = ActState<T|BMR>::stack();   // push processor state onto stack
        peer = next.resume();             // switch thread
        apr->clear();                     // pop processor state from stack
    } else {                  // save processor state into buffer variable...
        ActState<T|BMR> apr;              // save buffer for processor state
        apr.cache();                      // write processor state into buffer
        peer = next.resume();             // switch thread
        apr.apply();                      // read processor state from buffer
    }
    return peer;                          // return forerunner
}
```

Minimal System Extensions (cont.)

Bantamweight Thread — Use Case

```
#include "luxe/Flux.h"

#define STACKSIZE 256
#define LEEWAY 16

typedef Flux<Bantamweight> Fibre;

int main (int argc, char *argv[]) {
    char pool[STACKSIZE];                                 // spawnee stack space

    Fibre *son = new(pool, STACKSIZE - LEEWAY) Fibre;     // spawnee thread
    Act   *dad;                                           // spawner thread

    if ((dad = son->induce(son))) {                       // spawner clones
        for (;;) {                                        // spawnee has own state
            something();                                  // spawnee does its job
            dad = son->resume(*dad);                      // spawnee yields
        }
    }
    son = (Fibre*)((Fibre*)dad)->unwind(*son);            // spawner yields
    anything();                                           // spawner does its job
}
```

Family of Thread Abstractions

Memory Footprints of Fundamental Thread Switching Functions (IA-32)

weight class	static	dynamic	subtotal	total
straw	$8+7$	$4+4$		23
fly	$11+11$	$8+12$	42	65
bantam	$11+13$	$8+16$	48	71
feather	$11+7$	$8+32$	58	81
light	$11+19$	$8+28$	66	89

listed are...

- static (text, no data in this case) and dynamic (stack) requirements
- needs for function call (left term) and function body (right term)

From now on it's all plain sailing. . . ;-)

Functional Hierarchy of an Operating-System Family

layer	function	concept
10	program management	text, data, overlay
9	mass-storage management	partition, file, file system
8	process management	activity, context, stack
7	memory management	segment, page
6	information interchange	packet, message, channel, portal
5	device control	signal, character, block, stream
4	access protection	segment, page, domain, capability
3	resource sharing	lock, semaphore, monitor
2	job/task scheduling	energy, event, priority, time slice
1	control-flow exchange	coroutine, interrupt, continuation

A penny saved is a penny got. . .

Operating Systems for Embedded Systems

{BlueCat, HardHat} Linux, Embedix, Windows {CE, NT Embedded}, . . .

- not {adaptable, customizable, scalable, small, sparingly} enough

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. . . , BOSS, C{51, 166, 251}, CMX RTOS, Contiki, C-Smart/Raven, eCos, eRTOS, Embos, Ercos, Euros Plus, Hi Ross, Hynet-OS, ITRON, LynxOS, MicroX/OS-II, Nucleus, OS-9, OSE, OSEK {Flex, Plus, Turbo, time}, Precise/{MQX, RTCS}, proOSEK, pSOS, PURE, PXROS, QNX, Realos, RTMOSxx, Real Time Architect, RTA, RTOS-UH, RTXC, Softune, SOS, SSXS RTOS, ThreadX, TinyOS, VRTX, VxWorks, . . .

- over 50 % of OS for the embedded-systems market are proprietary

Summary

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- key to success: (embedded) operating system as a program family

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CiAO extends on PURE by an aspect-aware design

- focus is on increasing configurability by means of AOP
  - especially wrt. architectural and non-functional properties
- application of AOP principles from the very beginning
  - kernel developed in AspectC++