

“*Better Prevent Than Cure*”: Defensive Programming

Instructor: Peter Baumann

email: pbaumann@constructor.university

tel: -3178

office: room 88, Research 1

Credits:

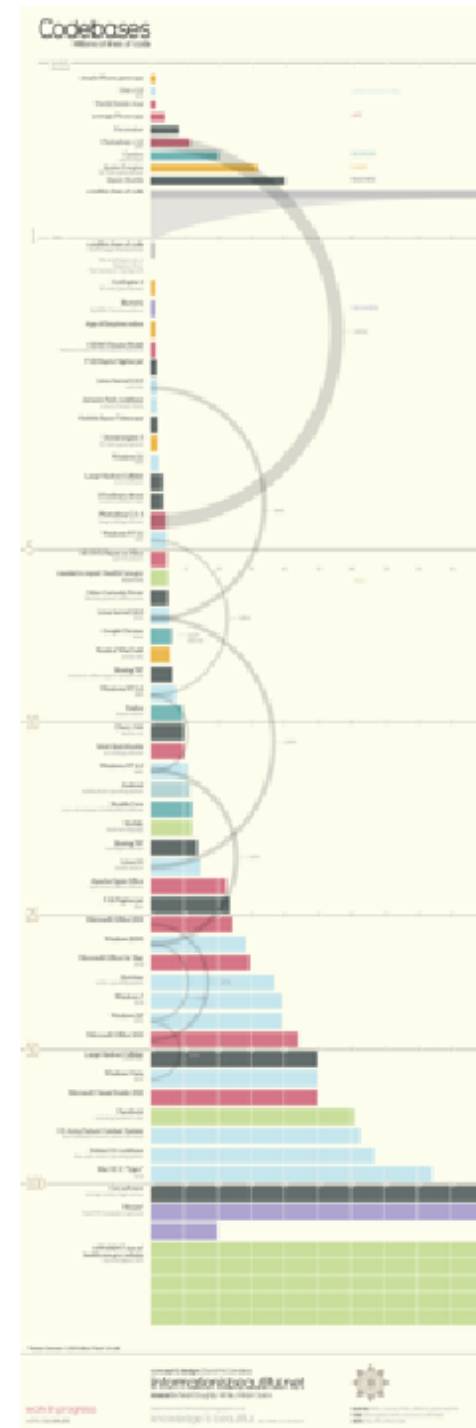
Fresh Sources Inc.

Cannot find REALITY.SYS.
Universe halted.

Big Code – Lines of Code

Average iPhone app	= 50.000 lines
Hubble Space Telescope	= 2 million lines
Windows 3.1 (1992)	= 2.5 million lines
Control software for US military drone	= 3.5 million lines
Windows NT 3.1 (1993)	= 4.5 million lines
HD DVD Player Xbox	= 4.5 million lines
World of Warcraft Server	= 5.5 million lines
Google Chrome	= 6.5 million lines
Windows NT 4 (1996)	= 11 million lines
MySQL	= 12 million lines
Boing 787 Flight Software	= 14 million lines
F35 Fighter jet	= 23 million lines
Microsoft Office 2013	= 44 million lines
Large Hadron Collider	= 50 million lines
Facebook	= 61 million lines
US Army Future Combat System	= 63 million lines
MacOS X 4.1 Tiger	= 85 million lines
Average high-end car	= 100 million lines
1.3+ million iPhone apps,	
1.3+ million Android apps	= 170billion lines

source: <http://www.informationisbeautiful.net/visualizations/million-lines-of-code/>



Big Data in Industry

- **Industry 4.0:** integration of production & IT
 - Optimising value chain & life cycle
- **Automobiles**
 - Networked with co-traffic, traffic lights, ... → PB a day
 - BMW iDrive:
 - *Onboard 40+ sensors, 30+ antennas*
 - *Gbit Ethernet, up to 30 Gb/s*
 - *5G → BMW Cloud*
- **Airplanes**
 - A380: 1b LoC
 - Per engine: 1 TB / 3 min
 - *LHR → JFK = 640 TB*

[Kristen Nicole]



[Airbus]



Software Crisis

- difficult to write **useful** & **efficient** computer programs in the required **time**
- Reason: rapid increases in computer power, complexity of problems that could be tackled
- Consequences:
 - Projects running over-budget, over-time
 - Software inefficient, of low quality, not meeting requirements
 - Projects unmanageable, code difficult to maintain
 - Software was never delivered

Software Extinction Events

- 1950s: assembler code not manageable
 - **symbolic PLs**: COBOL, FORTRAN

- 1960s: 100,000s LoC not manageable
 - **structured programming** [Dijkstra et al]:
 - *Bad stmts forbidden; blocks to enter at top & leave at bottom*
 - disentangled code → easier to read + test + maintain; measurable!

- 1980s: multi-millions LoC not manageable
 - **object orientation, UML**

- 2000s: proliferating Web services not manageable
 - **service-oriented architecture**: functional building-blocks accessible over standard Internet

Spaghetti Code

foo.h

```
#define BAR(x,y) (x)=2*(y)
#define FOO(x)   BAR(index,x)
```

foo.c

```
#include "foo.h"
int index = 42;

int f()
{
    int i;
    for ( i=0; i<10; i++ )
    {
        FOO(i);
        weirdStuff(index,i);
    }
}
```

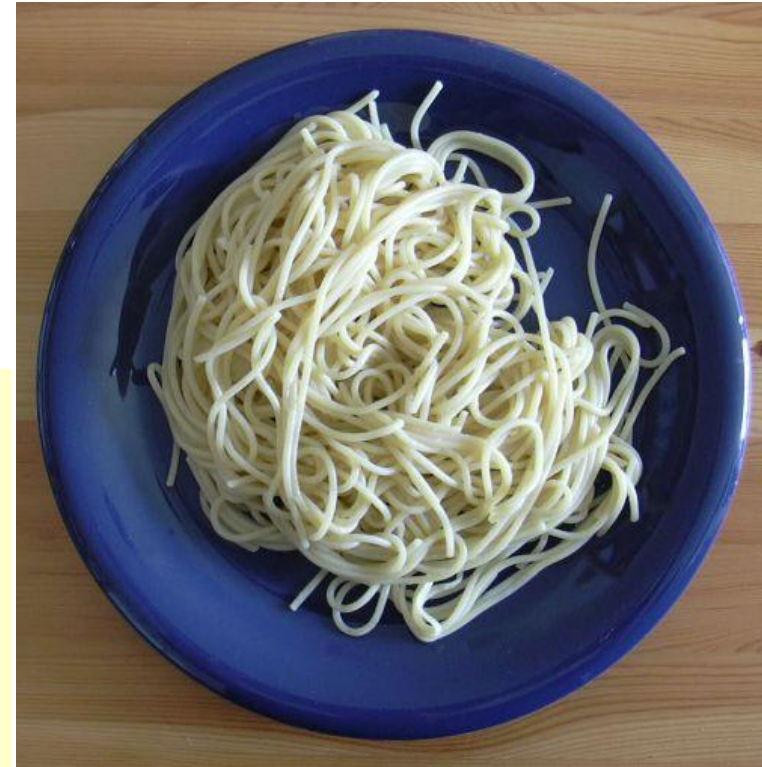


Image: Wikipedia
– check it out!

Now some "purist"
renames `i` to `index` ...

Software Crisis: Response

- Structured programming
 - Functions, blocks...all is better than **goto**!
 - Avoid spaghetti code
- Object-oriented programming
- Defensive programming
 - Better check twice
 - in particular across interfaces!
 - Runtime checks, safer PLs
- Correctness proofs
- Systematic testing

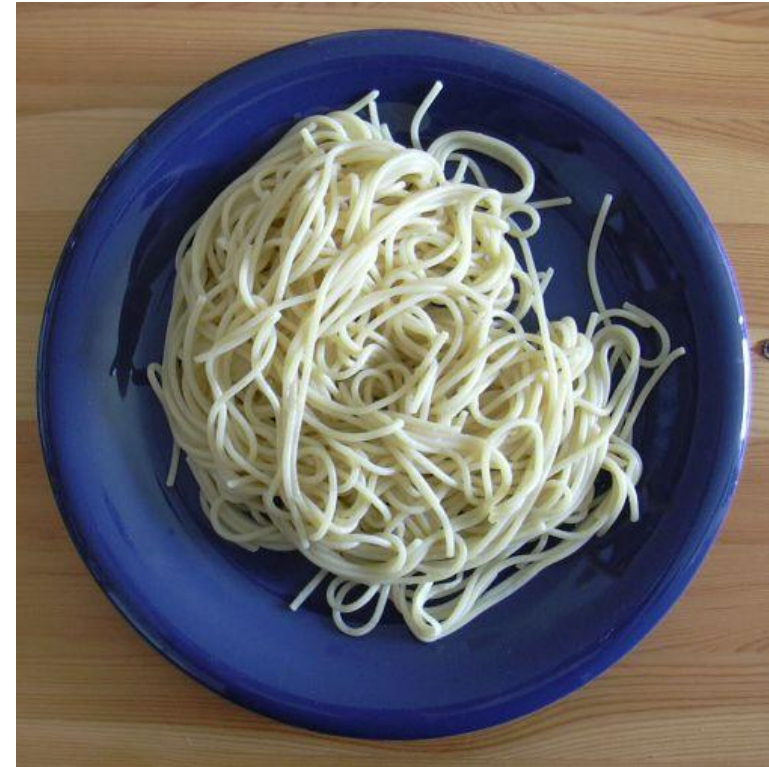


Image: Wikipedia
– check it out!

Defensive Programming

- Prevention is better than cure, therefore:
- Defensive Programming intends “to ensure the continuing function of a piece of software in spite of **unforeseeable** usage of said software”
 - [http://en.wikipedia.org/wiki/Defensive_programming]
- Good design yields better product
 - **Defending against errors** avoids lengthy debugging sessions
- Good design should be *evident* in code
 - Code is executable; comments aren't
 - Key design checkpoints should be **checked by your code**

Defensive Programming: Example

```
int risky_programming(char *input){
    char str[1000+1];
    // ...
    strcpy(str, input);
    // ...
}
```

```
int secure_programming(char *input){
    char str[1000];
    // ...
    strncpy(str, input, sizeof(str));
    str[sizeof(str) - 1] = '\0';
    // ...
}
```

[http://en.wikipedia.org/wiki/Defensive_programming]

Invariants

- Conditions that do not vary
 - “Design mileposts” in your code
- **Loop invariants**
 - True at beginning of each loop iteration (and after termination if all went well)
- **Class invariants**
 - True before and after each method call
- **Method invariants**
 - Pre- and post conditions
 - Part of “Design-by-contract”

Loop Invariant Example

- Program for computing the factorial of (integer) n:

Credit:
Alden Wright, U of Montana

```
unsigned int factorial( unsigned int n )
{
    unsigned int i = 1, fact = 1;
    while (i != n)
    {
        i++;
        fact *= i;
    }
    return fact;
}
```

Unsafe
– in practice, better use
while (i < n)

- Precondition: $n \geq 1$
- Postcondition: $\text{fact} == n!$

Loop Invariant Example (contd.)

- The loop invariant can be:
 - $fact = i!$
- Initialization:
 - Before first iteration: $i=1, fact=1 \Rightarrow fact=i!$
- Maintenance:
 - Let $i, fact$ denote values on previous iteration
 - Assume $fact = i!$, prove $fact=i!$
 - Proof:
 - $i = i + 1$ and $fact = fact * i$ // after loop body
 - $fact = i!$
 - $fact * i = i! * i$ // multiplying both sides by i
 - $fact = (i-1)! * i$
 - $fact = i!$
- Termination:
 - When loop terminates, $i = n$
 - This plus the loop invariant implies postcondition.
- Precondition necessary!

```
uint factorial( uint n )
{
    uint i = 1, uint fact = 1;
    while (i != n)
        i++, fact *= i;
    return fact;
}
```

Class Invariants

- All **constructors** should place their object in a valid state
- All **methods** should leave their object in a valid state
 - pre-condition and post-condition together should guarantee this
 - Better than just blind coding and testing!
- Example: **Rational** class:
 - `denominator > 0`
 - `gcd(num, den) == 1`

Method Invariants

- “Design by Contract”
 - Introduced by a Frenchman working in Switzerland living in California
- Methods are *contracts* with the user
- Users must meet **pre-conditions** of the method
 - Index in a certain range, for example
- Method guarantees **post-conditions**

Design by Contract: Example

- Users must meet method's pre-conditions:
 - “s is a string with length between 0 and SMAX-1”
 - “n is an integer between 0 and NMAX”
- drawback:
 - frequent “*still all ok?*” checks
 - But simple sequence, no deep “if” nesting

```
int myFunc( char *s, int n )
{
    int result = RC_OK;
    if (s == NULL)
        result = RC_INPUT_ERROR;
    else if (strlen(s) >= SMAX)
        result = RC_INPUT_ERROR;
    else if (n < 0 || n > NMAX)
        result = RC_INPUT_ERROR;

    if (result == RC_OK)
    {
        do_whatever_is_to_be_done;
    }

    return result;
}
```


Enforcing Invariants

– aka “Error Handling”

- Several techniques available, best usage depends...
- **assertions** = *force-terminate program*
 - For programmer errors that don't depend on end user, non-public member functions
- **exceptions** = *break flow of control (aka goto)*
 - For pre-conditions on **public** member functions
- **return codes** = *data-oriented, keep flow of control*
 - Post-conditions are usually a method's output

Assertions

- `assert()` macro
 - around since old C days
- if argument is false:
 - prints expression, file, and line number
 - then calls `abort()`
- Handling:
 - Enabled by default
 - Can **turn off** with `NDEBUG`:
 - `#define NDEBUG`
`#include <cassert>`

```
void MyVector::push_back( int x )
{
    if (nextSlot == capacity)
        grow();
    assert( nextSlot < capacity );
    data[ nextSlot++ ] = x;
}
```

- Brute force method
- **Never ever** use it in production!!!
 - *(would you like it in your editor?)*

Exceptions

- Interrupt regular flow of control, ripple up calling hierarchy
 - Until matching try/catch embrace
 - Otherwise abort program
- Exceptions are classes!
 - `throw()` instantiates exception object
 - can have parameters
 - catch sensitive per exception type
- Can have multiple `catch()`
 - `catch(...)` sensitive to any exception type

```
try
{
    s = myFunc();
}
catch (Error &e)
{
    // error log, file emergency close, ...
}
```

```
char *myFunc() throw (Error)
{
    char *myPtr = malloc( size );
    if (myPtr == NULL)
        throw new Error(ERR_BAD_ALLOC);
    return myPtr;
}
```

Return Codes

- Methods have a return parameter
 - For otherwise void result, it carries only success information
 - If method has regular result: reserve **otherwise unused** value
 - *NULL for strings, -1 for int, ...*
- It's an interface property
 - document clearly!
 - ...and check in caller code!
- Strongly recommended: single-return functions
 - use a local result variable!

```

int myFunc( string s, int n )
{
    int result = RC_OK;
    if (s == NULL)
        result = RC_INPUT_ERROR;
    else if (strlen(s) >= SMAX)
        result = RC_INPUT_ERROR;
    else if (n < 0 || n > NMAX)
        result = RC_INPUT_ERROR;
    if (result == RC_OK)
    {
        do_whatever_is_to_be_done;
    }
    return result;
}

```

Excursion: Another Real-Life Example

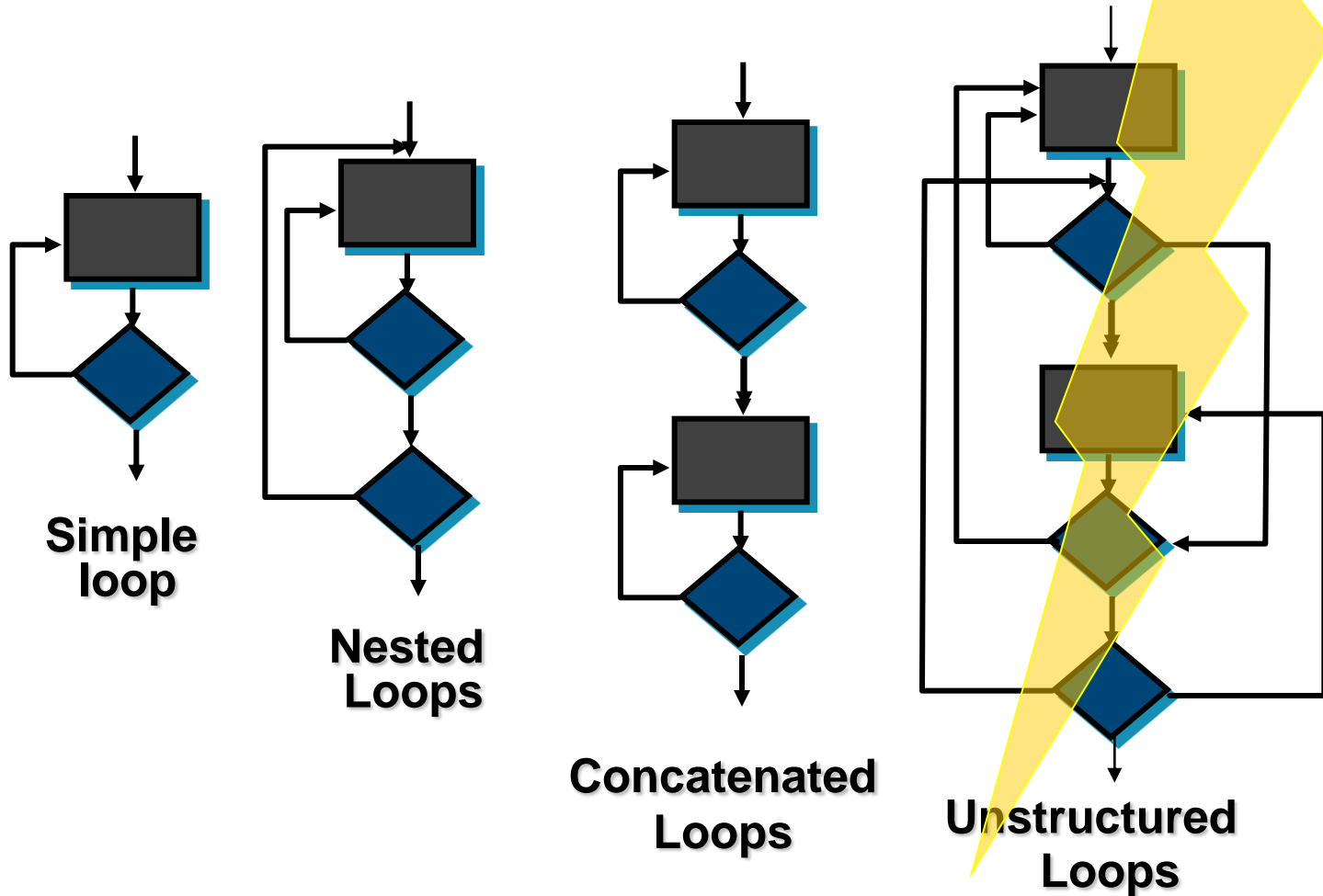
```
for ( count = 0, *templateList = myClass_New ( templateCount, char *);
    *templateList
    && count < templateCount
    && ( ( *templateList)[count] = aux_Duplicate (templates[count] ) );
    count++ );
```

- documenting this takes longer than writing a clear version of the code.
- no error handling at all!
- *How to do better?*

Structured Programming

- **Structured programming**
= component-level design technique [Dijkstra et al, early 1960s]
which uses **only small set of programming constructs**
- Principle: building blocks to enter at top & leave at bottom
 - **Good:** sequence(“;”); condition; repetition
 - **Bad:** (computed) goto; break; continue; ...
- Advantage: less complex code → **easier to read + test + maintain**
 - Measurable quality: small complexity (e.g., cyclometric)
 - *...but no dogma:* if it leads to excessive complexity, violating can be ok

Structured Programming: Loops



Apple 'goto fail' Bug [more]

```
static OSStatus SSLVerifySignedServerKeyExchange (
    SSLContext *ctx, bool isRsa, SSLBuffer signedParams,
    uint8_t *signature, UInt16 signatureLen )
{
    OSStatus err;
    . . .
    if (( err = SSLHashSHA1. update(&hashCtx , &serverRandom )) != 0)
        goto fail;
    if (( err = SSLHashSHA1. update(&hashCtx , &signedParams )) != 0)
        goto fail;
    goto fail;
    if (( err = SSLHashSHA1. final(&hashCtx , &hashOut )) != 0)
        goto fail;
    . . .
fail:
    SSLFreeBuffer(&signedHashes );
    SSLFreeBuffer(&hashCtx );
    return err;
}
```

- 2012 – 2014: Apple iOS SSL/TLS library falsely accepted faulty certificates
- Impersonation, man-in-the-middle attacks

use beautifiers!!!

Excursion: Expressing Control Flow

- Real-life example!
- **Nesting-bad.cc**: original code
 - how easy to follow & change?
- **Nesting-good.cc**: modified code
 - less lines, less columns, less nesting, less getting lost

Code Guides

- **Code guide**
= set of rules to which programmers must (should) adhere
 - Within company or project
- Twofold purpose:
 - Have **uniform style**
= less surprises = better learning curve for newbies
 - Codify **best practice**
= what is acknowledged to be advantageous
- *Varying, individual, maybe not all convincing...yet: **stick with it!***
- Let's see an example code guide...

Core Coding Rules

- **Reflect** before typing!
 - why are you doing what you are doing?
 - what is the best approach?
- Be **pedantic**
 - As far as ever possible, make it foolproof
 - No monkey tricks
 - Document!
- Design **cost-aware**
 - is it worth the effort?
 - Is it maintainable?

Tool Support: What Language?

- “Certain programming languages, including C/C++, enable bugs because of how the language was designed” – NIAG SG254
 - memory unsafety fixes: Microsoft 70%, Apple 66%, Android 90%, Chromium 70%
- Safety coding rules constraining allowable language constructs for:
 - Worst case memory & stack usage & analysis; Data coupling & control coupling analysis; Heap fragmentation; Code coverage & test coverage analysis; Object code analysis; memory & thread safety; Portability
- Overcoming C/C++: Ada, Rust, ...
 - Correctness: “if it compiles, then it works”
 - Strong typing semantics as well as the “ownership” and “borrowing” concepts
 - Null pointer safety, thread safety
 - High-level, zero-cost abstractions and language features resulting in clear & concise code

Summary

- Defensive Programming
= practises to **avoid** bugs upfront
- Helpful:
think in terms of assertions / contracts / pre- and postconditions / ...
 - Document and check preconditions for all public interfaces
 - Document postconditions (results, exceptions, ...) *and keep that promises*
- *How to write unmaintainable code:*
<http://mindprod.com/jgloss/unmain.html>
- Not addressed here: security
 - Signed config files & executables