C++ vs. C

the embedded perspective

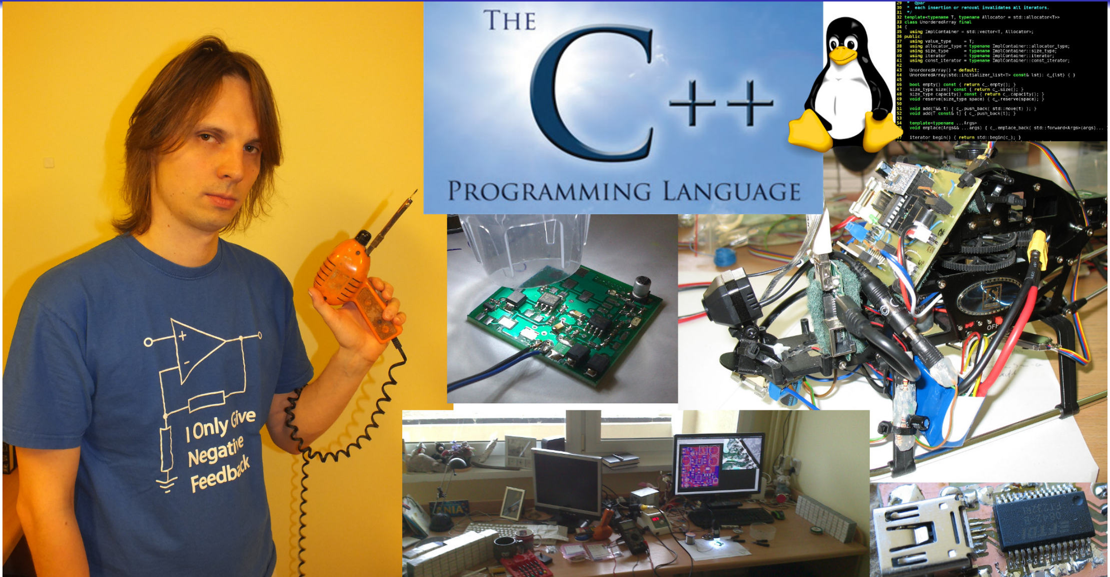
Bartek 'BaSz' Szurgot

http://www.baszerr.eu

2015-11-05

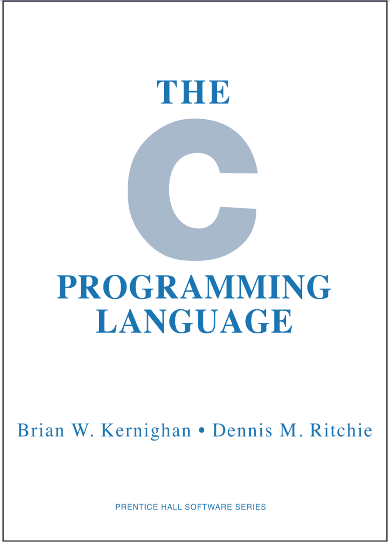
Code for food

Professional geek



```
 * @par
 * each insertion or removal invalidates all iterators.
 */
template<typename T, typename Allocator = std::allocator<T>>
class UnorderedArray final
{
  using ImplContainer = std::vector<T, Allocator>;
public:
  using value_type     = T;
  using allocator_type = typename ImplContainer::allocator_type;
  using size_type      = typename ImplContainer::size_type;
  using iterator       = typename ImplContainer::iterator;
  using const_iterator = typename ImplContainer::const_iterator;

  UnorderedArray() = default;
  UnorderedArray(std::initializer_list<T> const& lst): c_{lst} { }

  bool empty() const { return c_.empty(); }
  size_type size() const { return c_.size(); }
  size_type capacity() const { return c_.capacity(); }
  void reserve(size_type space) { c_.reserve(space); }

  void add(T&& t) { c_.push_back( std::move(t) ); }
  void add(T const& t) { c_.push_back(t); }

  template<typename ...Args>
  void emplace(Args&& ...args) { c_.emplace_back( std::forward<Args>(args)...

  iterator begin() { return std::begin(c_); }
```

Historically. . .



THE C PROGRAMMING LANGUAGE

Brian W. Kernighan • Dennis M. Ritchie

PRENTICE HALL SOFTWARE SERIES

https://upload.wikimedia.org/wikipedia/commons/9/95/The_C_Programming_Language%2C_First_Edition_Cover_%282%29.svg

Part 2

1. The experiment
2. Proving ground
3. Baseline
4. Flow control
5. Generic programming
6. Conclusions

Rules

- Year: 2005
- Software: GCC-3.x
- Hardware: x86

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- Hardware: x86
- Bet:
  - *C is faster than C++*
  - *No it’s not*
- Task:
  - Iterating array
  - Summing elements
  - Displaying result

Experimental code in C

```c
#include <stdint.h>

int main(void)
{
   const unsigned size = 2*1000*1000*1000;
   uint8_t* tab = (uint8_t*)malloc(size*sizeof(uint8_t));
   for(unsigned i=0; i<size; ++i)
       tab[i] = 3;
   unsigned out = 42;
   for(unsigned i=0; i<size; ++i)
       out += tab[i];
   free(tab);
   return out % 256;
}
```

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#include <algorithm>
#include <cstdint>
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int main(void)
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  const unsigned size = 2*1000*1000*1000;
  boost::scoped_array<uint8_t> tab(new uint8_t[size]);
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}
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Outcome?

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C++ over

3% **faster**

Surprise!

http://dailypicksandflicks.com/wp-content/uploads/2012/09/Day-33-they-still-suspect-nothing-Bobtail-Sheepdog-and-sheep-.jpg

What happened?

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- Abstract approach:

What happened?

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- Abstract approach:
  - STL
  - Opportunities!
- std::vector<uint8_t> too!
- Clang and GCC!
- Measurements, measurements. . .

Part 3

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Compilers’ settings

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- Common flags:
  - `-DNDEBUG`
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- Standards:
  - `-std=c++11`
  - `-std=gnu99`
- Flags for µCs:
  - `-fno-rtti`
  - `-fno-exceptions`

(a local wariant of) `https://upload.wikimedia.org/wikipedia/commons/d/dd/Buzz_salutes_the_U.S._Flag.jpg`

Optimization flags

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- Optimizing for size:
  - `-Os`

http://www.cashmanequipment.com/blog/wp-content/uploads/2012/02/Checkered-Flag4.jpg

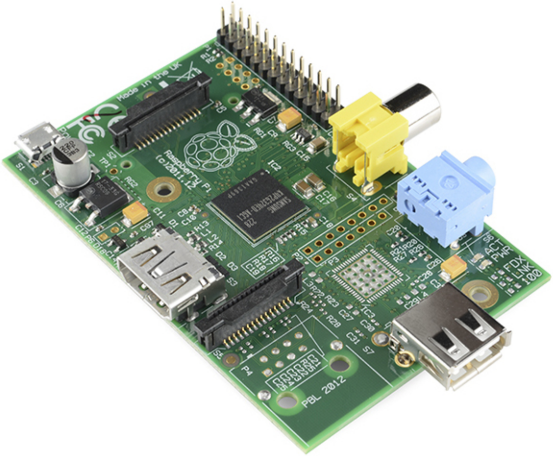
AMD64 (x86_64)

- "Modern PC"
- AMD FX8350
  - 64-bit
  - 4GHz
  - 32GB RAM
- Linux
- GCC-5.2.1
- Extra flags:
  - `-march=native`

http://www.hartware.de/media/reviews/1544/intro_hi.jpg

ARM-11

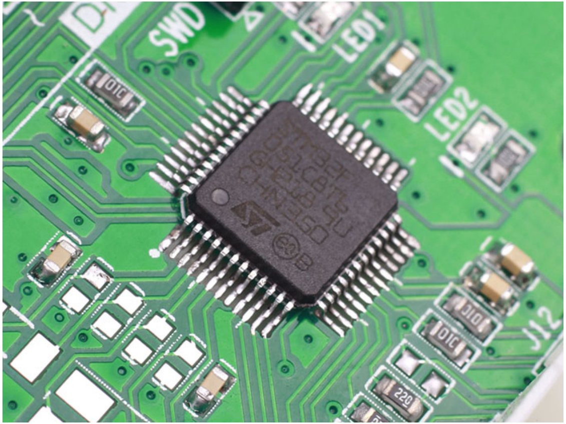
- Raspberry Pi
- ARM1176JZF-S (Broadcom)
  - 32-bit
  - 700MHz
  - 1GB RAM
- Linux
- GCC-5.2.1
- Extra flags:
  - `-march=native`



https://upload.wikimedia.org/wikipedia/commons/4/45/Raspberry_Pi_-_Model_A.jpg

ARM-M0

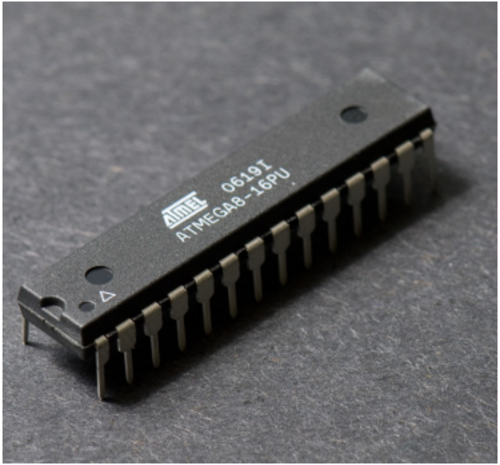
- "Mid-class" µC
- STM32F051 – Cortex M0 (STM)
  - 32-bit
  - 48MHz
  - 64kB flash
  - 8kB RAM
- No operating system
- GCC-4.9.3
- Extra flags:
  - `-mthumb`
  - `-mcpu=cortex-m0`



http://www.seeedstudio.com/depot/images/1029901720_02.jpg

AVR

- "Small" µC
- ATmega8 (Atmel)
  - 8-bit
  - 16MHz
  - 8kB flash
  - 1kB RAM
- No operating system
- GCC-4.8.1
- Extra flags:
  - `-mmcu=atmega8`



https://upload.wikimedia.org/wikipedia/commons/a/a9/ATmega8_01_Pengo.jpg

Runtime measurments

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int main()
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  // [...] - preparing test data
  measureStart();
  // [...] - actual code being measured
  measurePrint();
  measureSink(/* computed value */);
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- Size overhead?

Platform	Size [B]	LOC
AMD64	536	50
ARM-11	400	50
ARM-M0	1184	300
AVR	324	100

Part 4

1. The experiment
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Let’s start simple!

- C:

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int main()
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- C++:

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    - **libm.so.6** . . .
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    - libc.so.6 . . .
    - /lib64/ld-linux-x86-64.so.2 . . .
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- Key takeaways:
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  - Very few differences
  - A lot of "C-legacy"

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$$C \subset C{+}{+}$$

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- Key takeaways:
  - C++ – much bigger
  - Almost C-compatible
  - Very few differences
  - A lot of "C-legacy"
- "Over-linking" on PC. . . ;)
- No differences for µCs

C++ motto

You do not pay for what you do not use.

Part 5

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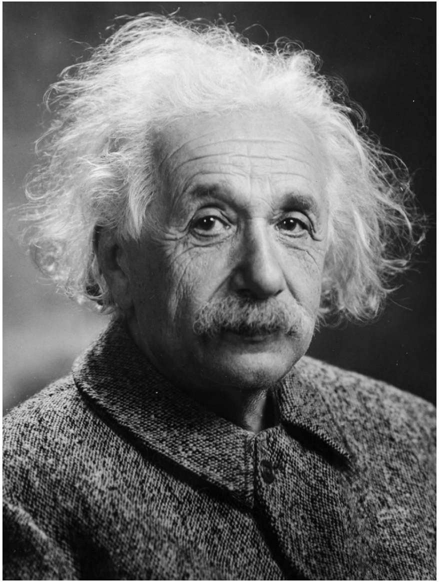
And now. . .

if()



`https://upload.wikimedia.org/wikipedia/commons/d/d3/Albert_Einstein_Head.jpg`

http://cdn.androidpolice.com/wp-content/uploads/2014/12/nexus2cee_50190-Have-you-tried-turning-it-off-HfqE_thumb.jpg

Errare humanum est. . .

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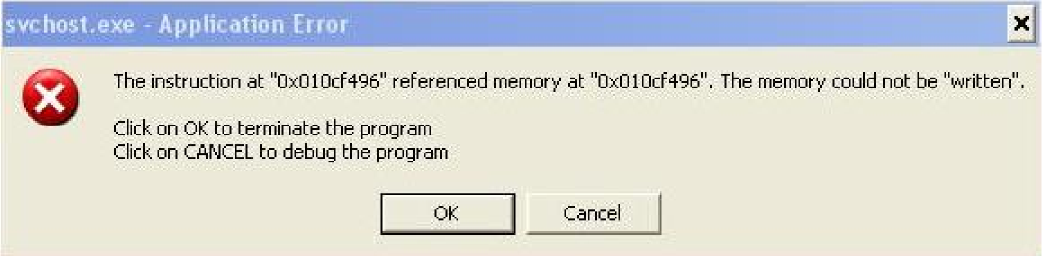

svchost.exe - Application Error

The instruction at "0x010cf496" referenced memory at "0x010cf496". The memory could not be "written".

Click on OK to terminate the program
Click on CANCEL to debug the program

http://1.bp.blogspot.com/-HzwyoFKILFQ/TZ0LlhQqcdI/AAAAAAAAAFE/qR201ehh2xg/s1600/svchost.exe+error.JPG

Error checking example – main.c(pp)

```
Data d;
d.param_    = magic;
d.hello_[0] = 'f';
d.hello_[1] = 'o';
d.hello_[2] = 'o';
Data* ptr = usePtr ? &d : 0;
int   out = magic;

for(int i=0; i<1000; ++i)
{
  if( magic != 1 )
    out = func1(ptr, out);
  if( magic != 2 )
    out = func2(ptr, out);
  if( magic != 3 )
    out = func3(ptr, out);
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- Runtime arguments:
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d.hello_[1] = ’o’;
d.hello_[2] = ’o’;
Data* ptr = usePtr ? &d : 0;
int   out = magic;

for(int i=0; i<1000; ++i)
{
  if( magic != 1 )
    out = func1(ptr, out);
  if( magic != 2 )
    out = func2(ptr, out);
  if( magic != 3 )
    out = func3(ptr, out);
}
```

- Data – parameter
- Random initialization
- Runtime arguments:
  - `magic`
  - `usePtr`
- Watch out for optimizations! ;)
  - LTO
  - Constant statements
  - Identical functions
  - ...

Error checking example – main.c(pp)

```
Data d;
d.param_     = magic;
d.hello_[0] = ’f’;
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- Data – parameter
- Random initialization
- Runtime arguments:
  - `magic`
  - `usePtr`
- Watch out for optimizations! ;)
  - LTO
  - Constant statements
  - Identical functions
  - ...
- C-compatible code:
  - Common implementation
  - Minimal differences

Error checking – simple case

- Functions' implementations:

```
int func1(Data* d, int in)
{
  if(!d)
    abort();
  if( d->param_ % 10 )
    d->param_ += 13;
  if( in > d->param_ )
    in -= 4;
  return (d->param_*in+1)
         % 1235;
}
```

```
int func2(Data* d, int in)
{
  if(!d)
    abort();
  d->param_ = (d->param_+12)
               % 75;
  return (d->param_+in/3*41)
         % 1206;
}
```

```
int func3(Data* d, int in)
{
  if(!d)
    abort();
  if(in>1000)
    in %= 999;
  for(int i=0; i<in; ++i)
  {
    d->param_ += in/2 - i;
    ++in;
    in *= 2;
  }
  return in + d->param_;
}
```

Error checking – simple case

- Functions’ implementations:

```
int func1(Data* d, int in)
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  if(!d)
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  if( d->param_ % 10 )
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int func3(Data* d, int in)
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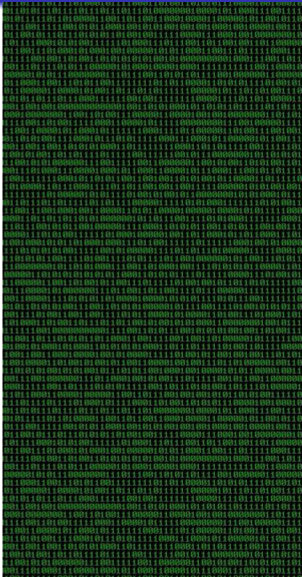
    in %= 999;
  for(int i=0; i<in; ++i)
  {
    d->param_ += in/2 - i;
    ++in;
    in *= 2;
  }
  return in + d->param_;
}
```

- Simplified view for measuring
- Error means `abort()`

Code size results

Platform	C [B]	C++ [B]
AMD64/nostdlib	5072	5080



Code size results

Platform	C [B]	C++ [B]
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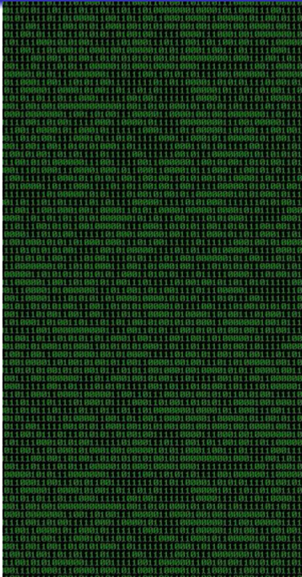

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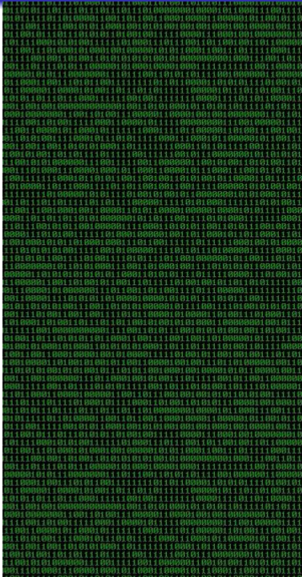

Code size results

Platform	C [B]	C++ [B]
AMD64/nostdlib	5072	5080
ARM-11	4248	3996
ARM-M0	4268	4264
AVR	958	958

http://upload.wikimedia.org/wikipedia/commons/thumb/c/cf/Binary_Code.jpg/1024px-Binary_Code.jpg

Can we do more with C++?

- So far:
  - Similar sizes
  - Similar code
  - Just another example. . .

Can we do more with C++?

- So far:
  - Similar sizes
  - Similar code
  - Just another example. . .
- Can we do more?
- With C++?
- Remember `if(!pointer)` problem?

```
int funcN(Data* d, int in)
{
  if(!d)          // hmm....
    abort();      // ...
  // bla..
  // bla..
  // bla..
  return 42;
}
```

Property type wrapper – non-nullptr pointer

```
template<typename P>
class NotNull final
{
public:
  explicit NotNull(P* p):
    p_{p}
  {
    if(not p_)
      abort();
  }

  P* operator->() const { return p_; }

private:
  P* p_;
};
```

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- Helper wrapper:
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  - Pointer is never `nullptr`
  - Arrow operator for syntax
  - Drop-in replacement

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  - Represents a pointer
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  - Arrow operator for syntax
  - Drop-in replacement
- Pointer checked in c-tor:
  - Just once – RAII-style
  - Type-guaranteed safely
  - No need for re-checking
- Simplistic
- Enough for tests

Applying the change

```
Data d;
d.param_     = magic;
d.hello_[0] = 'f';
d.hello_[1] = 'o';
d.hello_[2] = 'o';
NotNull<Data> ptr{ usePtr ? &d : 0 };
int    out = magic;

for(int i=0; i<1000; ++i)
{
  if( magic != 1 )
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```

```
int funcN(NotNull<Data> d, int in)
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  // bla..
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int    out = magic;

for(int  i=0;  i<1000; ++i)
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  if(  magic != 1  )
    out = func1(ptr,  out);
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int funcN(NotNull<Data> d, int in)
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  // bla..
  // bla..
  return 42;
}
```

- Simple refactoring
- Compiler supported
- Less code! :D

Less code. . .

http://memecrunch.com/meme/62H3/happy-cat/image.png

Results – sizes

- Old results copied for reference

Platform	C [B]	C++ [B]	C++/NotNull [B]
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- New type – decreased size!
- Templates ≠ footprint. . .

Results – speed

Platform	C	C++	C++/NotNull
AMD64 [μs]	31 ± 6	29 ± 5	30 ± 7

Results – speed

Platform	C	C++	C++/NotNull
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AMD64 [*μs*]	31 ± 6	29 ± 5	30 ± 7
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AVR [*cycles*]	1,493,926	1,493,926	1,471,556

- C++ and C – equal
- `NotNull`:
  - No/small difference on Linux
  - 2% gain on µCs
- Templates ≠ footprint. . .

Faster by encapsulation

- **Faster by encapsulation** approach:
  - Faster execution time
  - Faster development
  - Faster testing

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- General approach
- Good practice to avoid errors

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- **Faster by encapsulation** approach:
  - Faster execution time
  - Faster development
  - Faster testing
- Smaller binary – free lunch!
- Mixture of techniques
- General approach
- Good practice to avoid errors
- Field-tested
- `NotNull<>` available as OS:
- `https://github.com/el-bart/but/blob/master/But/NotNull.hpp`

http://www.blowfieldbikers.be/wp-content/uploads/2011/06/hellyeah.jpg

Part 6

1. The experiment
2. Proving ground
3. Baseline
4. Flow control
5. Generic programming
6. Conclusions

Example task

- Computing 4 medians
- 4 input arrays:
  - 2 of `ints`
  - 2 of `doubles`
  - 10 elements each

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Example task

- Computing 4 medians
- 4 input arrays:
  - 2 of `int`s
  - 2 of `double`s
  - 10 elements each
- Approach:
  - Sort input array
  - Select middle element
- Bubble sort

https://upload.wikimedia.org/wikipedia/commons/9/94/Reflection_in_a_soap_bubble_edit.jpg

C++ (templates)

```
template<typename T>
T arrayMedian(T* tab, int size)
{
  for(int i=0; i<size; ++i)
  {
    auto changed = false;
    for(int j=1; j<size; ++j)
    {
      if(tab[j-1] > tab[j])
      {
        swap(tab[j-1], tab[j]);
        changed = true;
      }
    }
    if(not changed)
      break;
  }
  return tab[size/2];
}
```

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- Swapping:

```cpp
template<typename T>
void swap(T& a, T& b)
{
  T tmp = a;
  a = b;
  b = tmp;
}
```

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- Swapping:

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template<typename T>
void swap(T& a, T& b)
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  T tmp = a;
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  b = tmp;
}
```

- Automatic array size deduction:

```
template<typename T, int N>
T arrayMedian(T (&tab)[N])
{
  return arrayMedian(tab, N);
}
```

C (macros)

```
#define ARRAY_MEDIAN(tab, out, tmp) \
  do \
  { int size=sizeof(tab)/sizeof(tab[0]); \
    for(int i=0; i<size; ++i) \
    { \
      int changed = 0; \
      for(int j=1; j<size; ++j) \
      { \
        if(tab[j-1] > tab[j]) \
        { \
          tmp      = tab[j-1]; \
          tab[j-1] = tab[j]; \
          tab[j]   = tmp; \
          changed  = 1; \
        } \
      } \
      if(!changed) \
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    } \
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  } while(0)
```

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https://pugnaciousirishman.files.wordpress.com/2008/12/vogons22.jpg

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https://pugnaciousirishman.files.wordpress.com/2008/12/vogons22.jpg

main()s

```
// C implementation:
int    n1[10] = { /*...*/ };
int    n2[10] = { /*...*/ };
double d1[10] = { /*...*/ };
double d2[10] = { /*...*/ };

int tmpInt;
double tmpDouble;

int out1;
ARRAY_MEDIAN(n1, out1, tmpInt);
int out2;
ARRAY_MEDIAN(n2, out2, tmpInt);
double out3;
ARRAY_MEDIAN(d1, out3, tmpDouble);
double out4;
ARRAY_MEDIAN(d2, out4, tmpDouble);
```

main()s

```
// C implementation:
int    n1[10] = { /*...*/ };
int    n2[10] = { /*...*/ };
double d1[10] = { /*...*/ };
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int tmpInt;
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- Surprised? :)
- . . . How about speed?

https://upload.wikimedia.org/wikipedia/commons/3/37/African_Bush_Elephant.jpg

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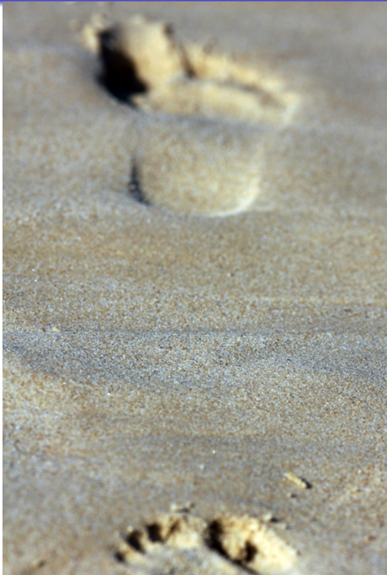
https://upload.wikimedia.org/wikipedia/commons/1/1d/Turtle3m.JPG

Observations

- C++ templates outperformed C macros
- C++ templates smaller than C macros



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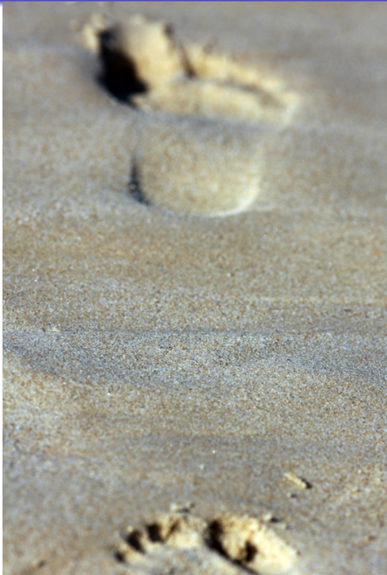

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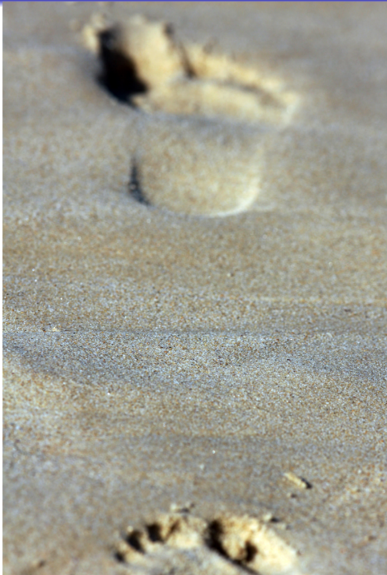

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- C lacks good support for generic code:
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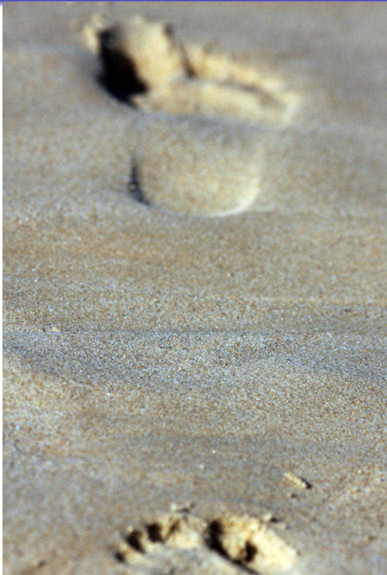
  - `void*` API?
  - LTO often helps



https://upload.wikimedia.org/wikipedia/commons/2/24/Big_Foot_%286225546731%29.jpg

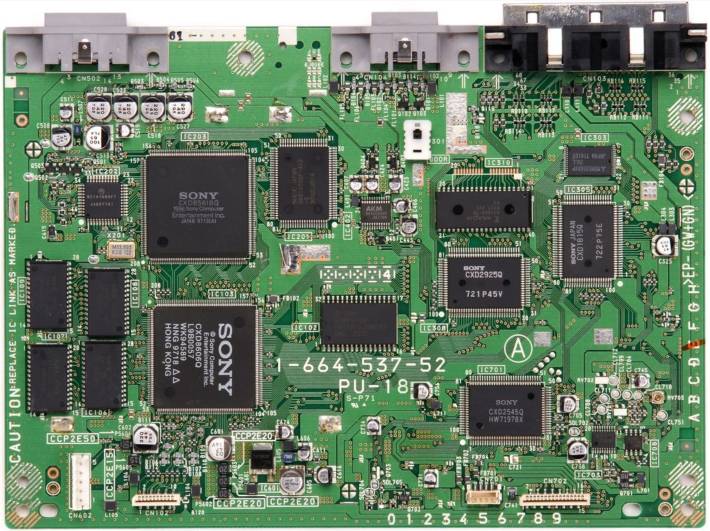
Part 7

1. The experiment
2. Proving ground
3. Baseline
4. Flow control
5. Generic programming
6. Conclusions

Software optimizations

https://upload.wikimedia.org/wikipedia/commons/a/af/GNU_Compiler_Collection_logo.svg
https://upload.wikimedia.org/wikipedia/en/4/4c/LLVM_Logo.svg

Meet the hardware!



https://upload.wikimedia.org/wikipedia/commons/d/d7/PSX-SCPH-5001-Motherboard.jpg

Working with optimizations

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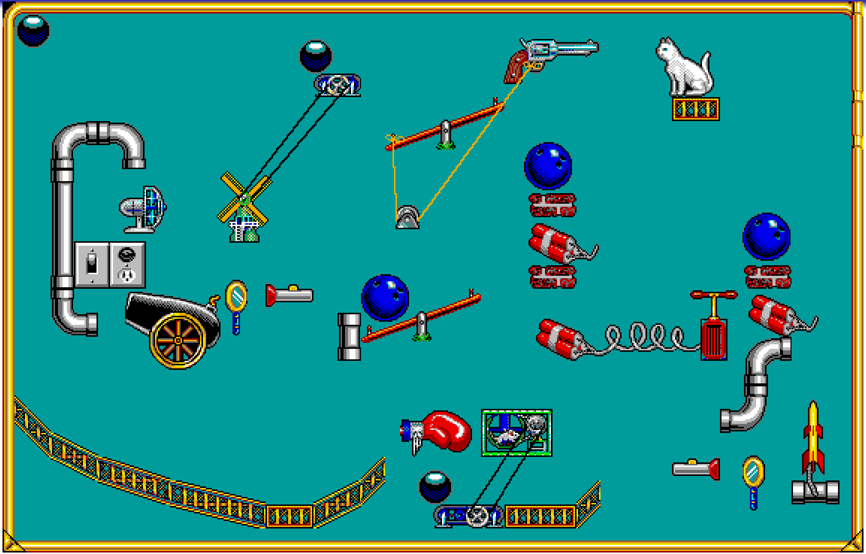
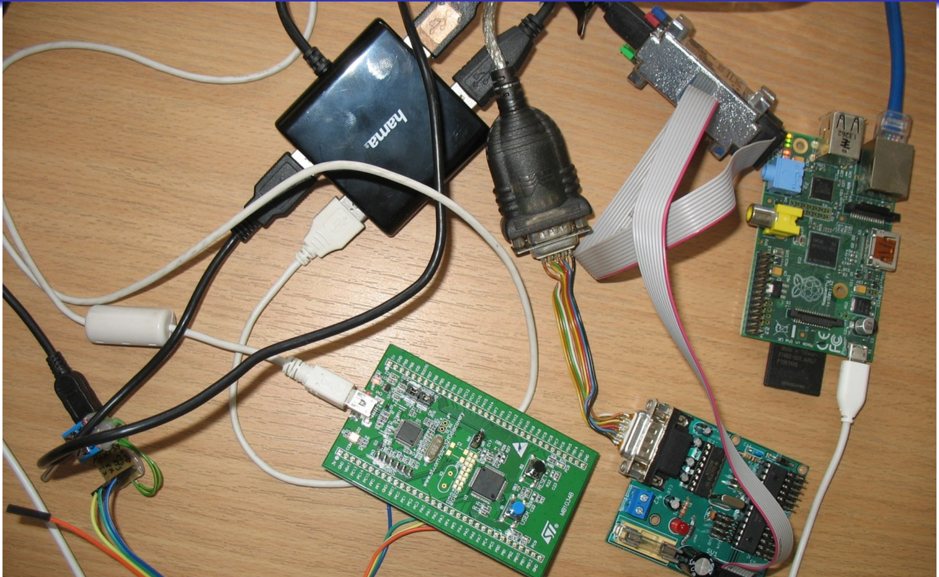


http://sfprod.shikadi.net/old/pic/timss.png

Testing time!



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#include <iostream>
#include <boost/network/protocol/http/client.hpp>
using boost::network::http::client;
int main()
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  client          client;
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- Standard library grows
- "Do not pay for what you do not use"
- Embedded-friendly. . .

"Door light" project

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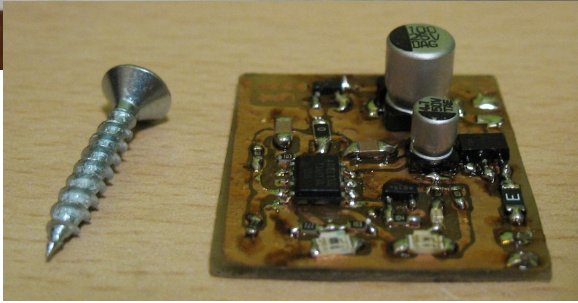
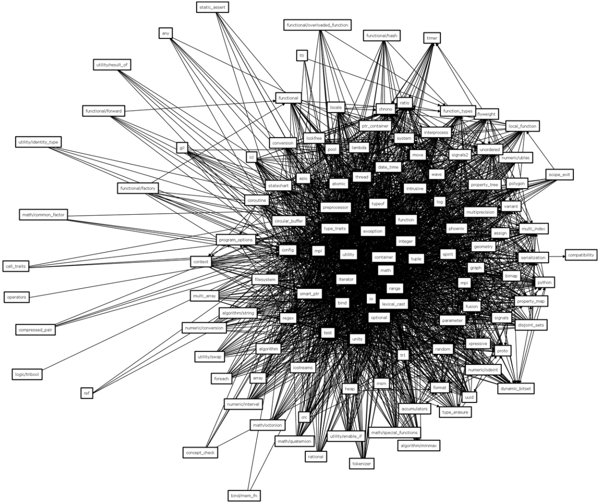


- AVR ATtiny13:
  - 1024 [B] ROM
  - 64 [B] RAM
  - 1 [MHz] (RC oscillator)

Other materials

- "*Real-Time C++: Efficient Object-Oriented and Template Microcontroller Programming*", 2013
  Christopher Kormanyos
- "*The C++ Programming Language*", 2013
  Bjarne Stroustrup
- "*Technical Report on C++ Performance - Open Standards*", 2004
  `http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2004/n1666.pdf`
- "*Hello Houston, czyli rzecz o błędów zgłaszaniu*", 2013
  `http://baszerr.eu/lib/exe/fetch.php/docs/hello_houston.pdf`
- "*Życie bez #ifdefów*", 2013
  `http://baszerr.eu/lib/exe/fetch.php/docs/zycie_bez_ifdefow.pdf`
- "*Effective modern C++*", 2015
  Scott Meyers
- Door light project, 2013
  `http://baszerr.eu/doku.php/prjs/door_light/door_light`

Questions?



http://www.meetingcpp.com/tl_files/blog/bda/boost154_libxml.png

Coming up next year!

VS

https://upload.wikimedia.org/wikipedia/commons/9/9f/Vimlogo.svg
https://upload.wikimedia.org/wikipedia/commons/5/5f/Emacs-logo.svg