SMIL : Simple Morphological Image Library

Matthieu Faessel, Michel Bilodeau

Centre de Morphologie Mathématique, Mathématiques et Systèmes,
MINES ParisTech

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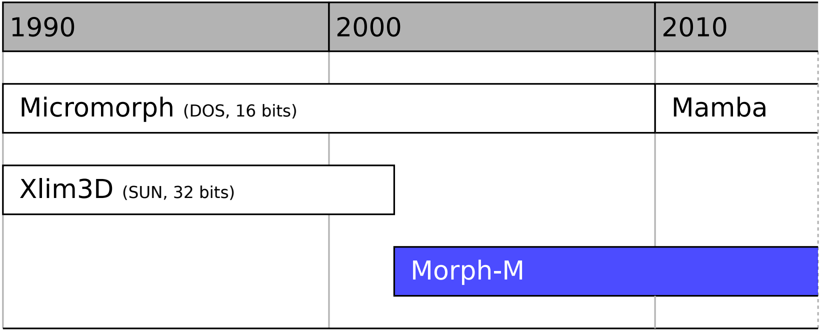
CMM image libraries history



Morph-M: a research library

Advantages: suitable for exploration

- Generic (gray, color, multispectral images, graphs, . . .)
- N-Dimensions
- Meta-programming
- A lot of contributions (common workspace for students, researchers, . . .)

Drawbacks

- Developement time
- Clarity of the code (for users and contributors): a high level of abstraction
- **Performances**: not in the initial specifications, very difficult to integrate afterwards
- Proprietary Licence: not very flexible for industrial projetcs

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New constraints

Industrial projects with performance constraints increasingly strong

- Real-time applications (ex: industrial control, video surveillance)
- Near real-time processing of large 2D images (ex: $40.000 \times 1.200/sec$)
- 3D images (ex: $1.000^3 \rightarrow 1\ GPix$)
- Embedded systems

New needs

- Very fast algoritms / Support for large data
- Relatively light
- Easy prototyping
- Ease of integration

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New needs

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- Relatively light
- Easy prototyping
- Ease of integration

Fast Morph-M alternatives

Mamba

Pros:

✓ Fast (intrinsic SIMD functions)

✓ Easy to use (python, embedded viewer, . . .)

✓ Implementation of new python functions is simple

Cons:

✗ Most functions are written in python (with dependency with other python libraries) ⇒Problems for integration

✗ C based Core: no factorization (much redundant code)⇒Rigidity, not suitable for general improvements or newer developpements

✗ SIMD intrinsic functions: a lot of code lines

Fast Morph-M alternatives

Fulguro

Pros:

✓ Fast (intrinsic SIMD functions)

✓ C-style factorization (macros)

Cons:

✗ C-style factorization (macros)

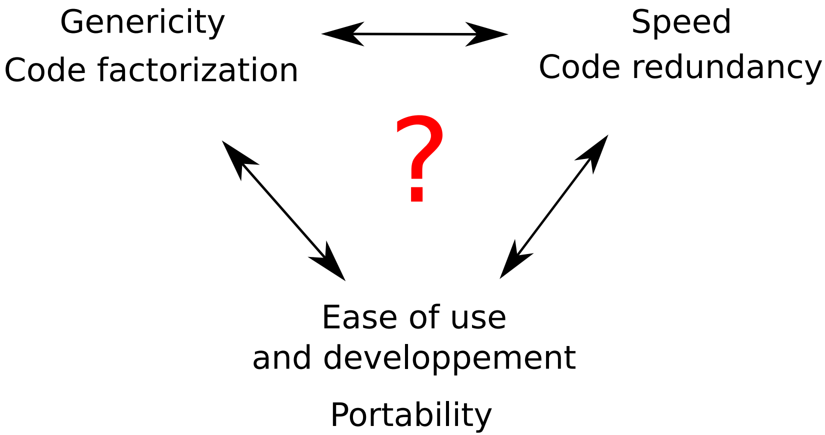
✗ SIMD intrinsic functions: a lot of code lines

Fast-MorphM

MorphM SIMD Addon

Very few functions

A solution ?


Genericity
Code factorization
Speed
Code redundancy
?
Ease of use
and developpement
Portability

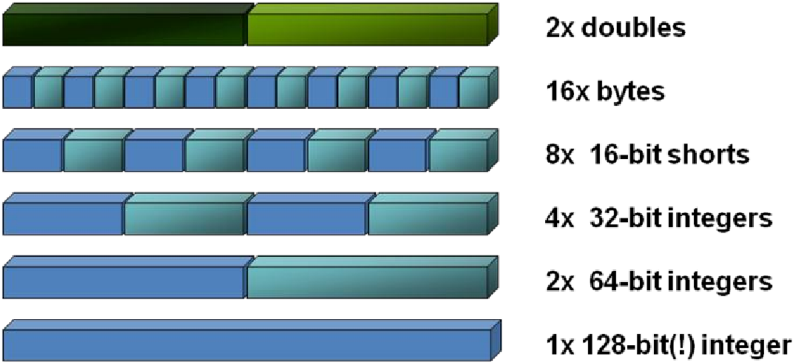
A new done: Auto-Vectorization

GCC 4.2 new feature: auto-vectorization... reconciliates C++ and SIMD

⇒Start a new library from scratch, using auto-vectorization

Vectorization

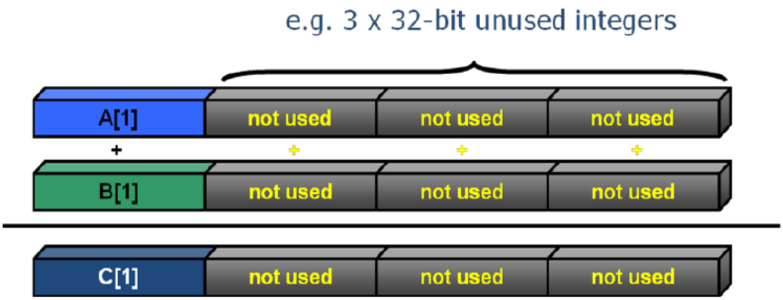
SIMD Registers



Vectorization

```
for(i=0;i<=MAX;i++)
    c[i]=a[i]+b[i];
```

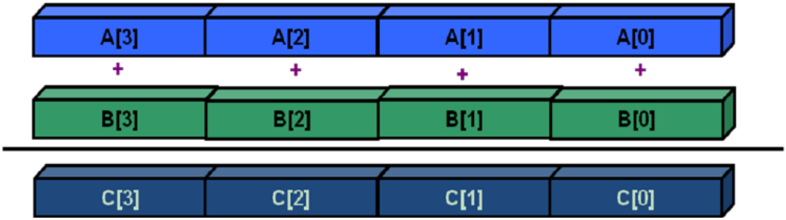
Not vectorized



Vectorization

```
for(i=0;i<=MAX;i++)
    c[i]=a[i]+b[i];
```

Vectorized



How to vectorize ?

- Until auto-vectorization: Intrinsic implementation
  - Requires aligned and contiguous data
  - 1 implementation/data type
  - 1 implementation/SIMD instruction type (SSE, SSE2, . . .)
- With auto-vectorization
  - Requires auto-vectorization capable compiler: GCC ($\geq$4.2), ICC, XLC, CLang, MSVC ($\geq$2012), . . .
  - Requires ~~aligned and~~ contiguous data
  - Requires some code conditions: write vectorizer-friendly code:
    - Countable loop
    - Avoid aliasing problems (single entry and single exit)
    - Straight-line code
    - The innermost loop of a nest
    - No function calls

Auto-vectorization Example

```
\    #define N 128
1.   int a[N], b[N];
2.   void foo (void)
3.   {
4.   int i;
5.
6.   for (i = 0; i < N; i++)
7.     a[i] = i;
8.
9.  for (i = 0; i < N; i+=5)
10.       b[i] = i;
11. }
```

```
ex.c:7: note: LOOP VECTORIZED.
ex.c:3: note: vectorized 1 loops in function.
ex.c:10: note: not vectorized: complicated access pattern.
```

Generated Assembler Code

SSE2 vecteurs et scalaires

```
void supLine(const PIXEL *pIn1,
             const PIXEL *pIn2,
             PIXEL *pOut, int count){
   {
   for (int i=0; i< count; i++){

       pOut[i] =
          MAX(pIn1[i], pIn2[i]);
   }
}
```

```
L4:
movdqu (%rsi,%rax), %xmm0
addl $1, %r8d
movdqu (%rdi,%rax), %xmm1
pmaxub %xmm1, %xmm0
movdqu %xmm0, (%rdx,%rax)
addq $16, %rax
cmpl %r8d, %r9d
    ja L4
```

```
L6:
movzbl (%rdi,%rax), %edx
movzbl (%r10,%rax), %esi
cmpb %dl, %sil
cmovae %esi, %edx
movb %dl, (%r9,%rax)
addq $1, %rax
leal (%r8,%rax), %edx
cmpl %edx, %ecx
    jg L6
```

Generated Assembler Code

SSE2

```
void supLine(const PIXEL *pIn1,
             const PIXEL *pIn2,
             PIXEL *pOut, int count){
   {
   for (int i=0; i< count; i++){

       pOut[i] =
          MAX(pIn1[i], pIn2[i]);
   }
}
```

```
L4:
movdqu (%rsi,%rax), %xmm0
addl $1, %r8d
movdqu (%rdi,%rax), %xmm1
pmaxub %xmm1, %xmm0
movdqu %xmm0, (%rdx,%rax)
addq $16, %rax
cmpl %r8d, %r9d
 ja L4
```

Generated Assembler Code

vmax

```
void supLine(const PIXEL *pIn1,
             const PIXEL *pIn2,
             PIXEL *pOut, int count){
   {
   for (int i=0; i< count; i++){

       pOut[i] =
          MAX(pIn1[i], pIn2[i]);
   }
}
```

```
L4:
vmovdqu (%rsi,%rax), %xmm1
addl $1, %r8d
vmovdqu (%rdi,%rax), %xmm0
vpmaxub %xmm0, %xmm1, %xmm0
vmovdqu %xmm0, (%rdx,%rax)
addq $16, %rax
cmpl %r8d, %r9d
    ja L4
```

Generated Assembler Code

vmax2

```
void supLine(const PIXEL *pIn1,
             const PIXEL *pIn2,
             PIXEL *pOut, int count){
   {
   for (int i=0; i< count; i++){

       pOut[i] =
          MAX(pIn1[i], pIn2[i]);
   }
}
```

```
L16:
vmovdqu (%rsi,%rax), %xmm1
addl $1, %r8d
vmovdqu (%rdi,%rax), %xmm0
vinserti128 $0x1, 16(%rsi,%rax), %ymm1, %ymm1
vinserti128 $0x1, 16(%rdi,%rax), %ymm0, %ymm0
vpmaxub %ymm0, %ymm1, %ymm0
vmovdqu %xmm0, (%rdx,%rax)
vextracti128 $0x1, %ymm0, 16(%rdx,%rax)
addq $32, %rax
cmpl %r8d, %r9d
ja L16
```

Generated Assembler Code

boucle while

```
void supLine(const PIXEL *pIn1,
             const PIXEL *pIn2,
             PIXEL *pOut,
             int count)
 {

    while(count--) {

        *pOut++  =
            MAX(*pIn1, *pIn2);
        pIn1++;pIn2++;
    }
}
```

```
L16:
vmovdqu (%rsi,%rax), %xmm1
addl $1, %r8d
vmovdqu (%rdi,%rax), %xmm0
vpcmpgtq %xmm0, %xmm1, %xmm2
vpblendvb %xmm2, %xmm1, %xmm0, %xmm0
vmovdqu %xmm0, (%rdx,%rax)
addq $16, %rax
cmpl %r8d, %r9d
ja L16
```

Generated Assembler Code

boucle while avec fonction compteur

```
int countDecr(int count){
    return count-1;
}
void supLine(const PIXEL *pIn1,
             const PIXEL *pIn2,
             PIXEL *pOut,
             int count)
 {

    while(count) {

        *pOut++  =
            MAX(*pIn1, *pIn2);
        pIn1++;pIn2++;
        count = countDecr(count);
    }
}
```

```
L17:
movq (%r12,%rbx), %rcx
movl %eax, %edi
movq 0(%r13,%rbx), %r8
cmpq %rcx, %r8
cmovge %r8, %rcx
movq %rcx, 0(%rbp,%rbx)
addq $8, %rbx
call __Z9countDecri
testl %eax, %eax
jne L17
```

1. Introduction
2. SMIL: General presentation
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SMIL: General

Base Objectives

- Speed
- Flexible licence
- Ease of integration:
  - Light
  - No major dependancy
  - Multi-platforms/compilers

Additionnal Objectives

- Easy to use
- Easy to develop/extend
- A lot of factorization:
  - Less code to write
  - Facilitates major evolutions
  - Concentrate optimizations parts

SMIL: Ingredients

- C++
- Templates, but no real genericity (non-standard types require specializations)
- Auto-vectorization
- OpenMP
- CMake
- Swig
- (doxygen, git)
- BSD Licence

Templates and Vectorization

Intrinsic Specializations

Sup_....cpp

#ifdef __SSE

Sup_UINT16.cpp

#ifdef __SSE

Sup_UINT8.cpp

```
#ifdef __SSE__
   template<>
   inline void t_LineArithSup1D<UINT8>(...) {
     int i;
     __m64 r0,r1;

     for(i=0 ; i<=size ; i+=8)  {
         r0 = *((__m64 *) linein1);
         r1 = *((__m64 *) linein2);
         r1 = _mm_max_pu8(r0,r1);
          *((__m64 *) lineout) = r1;

         linein1 += 8;
         linein2 += 8;
         lineout += 8;
     }
   }
#else
#ifdef __SSE2__
   template<>
   inline void t_LineArithSup1D<UINT8>(...) {
     int i;
     __m128i r0,r1;

     for(i=0 ; i<=size ; i+=16)  {
         r0 = _mm_load_si128((__m128i *) linein1);
         r1 = _mm_load_si128((__m128i *) linein2);
         r1 = _mm_max_epu8(r0,r1);
         _mm_store_si128((__m128i *) lineout,r1);

         linein1 += 16;
         linein2 += 16;
         lineout += 16;
```

Templates and Vectorization

Intrinsic Specializations

Sup_....cpp

#ifdef __SSE__

Sup_UINT16.cpp

#ifdef __SSE__

Sup_UINT8.cpp

```
#ifdef __SSE__
  template<>
  inline void t_LineArithSup1D<UINT8>(...) {
    int i;
    __m64 r0,r1;

    for(i=0 ; i<=size ; i+=8)  {
        r0 = *((__m64 *) linein1);
        r1 = *((__m64 *) linein2);
        r1 = _mm_max_pu8(r0,r1);
         *((__m64 *) lineout) = r1;

        linein1 += 8;
        linein2 += 8;
        lineout += 8;
    }
  }
#else
#ifdef __SSE2__
  template<>
  inline void t_LineArithSup1D<UINT8>(...) {
    int i;
    __m128i r0,r1;

    for(i=0 ; i<=size ; i+=16)  {
        r0 = _mm_load_si128((__m128i *) linein1);
        r1 = _mm_load_si128((__m128i *) linein2);
        r1 = _mm_max_epu8(r0,r1);
        _mm_store_si128((__m128i *) lineout,r1);

        linein1 += 16;
        linein2 += 16;
        lineout += 16;
```

With Auto-Vectorization

Sup.cpp

```
template <class T>
struct supLine : public binaryLineFunctionBase<T>
{
  typedef typename Image<T>::lineType lineType;
  inline void _exec(lineType lIn1, lineType lIn2, size_t size, lineType lOut)
  {
    for (size_t i=0;i<size;i++)
      lOut[i] = lIn1[i] > lIn2[i] ? lIn1[i] : lIn2[i];
  }
};
```

CMake

Cross-platform native makefiles and workspaces generator

- Allows to build the sources on almost any platform and with any compiler
- Facilitates cross-compilation
- Handles compilation options (external libs, optimizations, documentation, . . .)
- Handles wrapped languages and types

Current tested platforms:

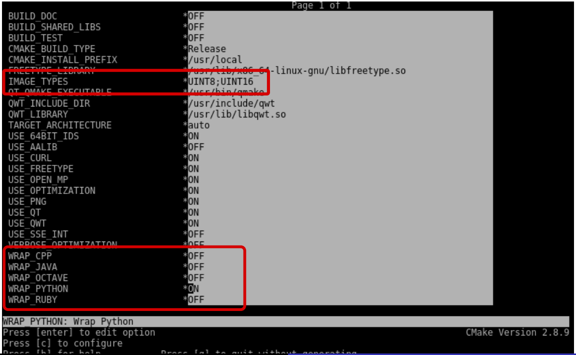
- Linux (32/64 bits) - GCC
- Windows (32/64 bits) - GCC, MSVC (without auto-vectorization)
- OSX - GCC, Clang
- Android

Swig

Current SMIL version allows to generate interfaces for **Java, Python, Octave and Perl**.

Generated code have the same function names and arguments as original C++ code.

The wrapped types and languages are defined via CMake.



Why Simple ?

Easy to use

- Simple framework (only 2D/3D images, no complex structures due to genericity)
- $\sim$13,000 code lines (MorphM: $\sim$130,000)
- Multi-platforms, multi-compilers (CMake)
- Serveral possible languages/interpreters with common native C++ code and the same function names and arguments (swig): python, java, octave, perl, . . .
- Integrated viewer, events management
- Simple and short function names
- Intuitive approach:
  - functions overload
  - operators overload
- webstart version, . . .

Examples of use

 # Load an image

im1 = Image()
im1 << "lena.png"
im1.show()

Equivalent to

read("lena.png", im1)

 # Mask of values > 100

im2 = Image(im1)
im2 << ((im1>100) & im1)
im2.show()

# Equivalent to
grt(im1, 100, im2)
inf(im1, im2, im2)

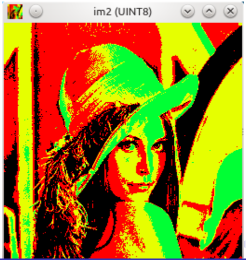
Examples of use

```
# Sup of translations...
im3 = Image(im1)
sePts = ((0,0),(0,1),(1,1),(1,0),(-1,1),(-1,0),(-1,-1),(0,-1),(1,-1))
im3 << 0
for (dx,dy) in sePts:
   im3 |= trans(im1, dx, dy)
im3.show()
```

Examples of use

Some thresholds

```
# Fixed threshold
threshold(im1, 100, 255, im2)
# Otsu (2 modalities)
threshold(im1, im2)
# Otsu (3 modalities)
otsuThreshold(im1, im3, 3)
im3.showLabel()
```



Why Simple ?

Effort to factorize as much as possible

- line functors
- image functors (standard operations, morphological operations, . . .)
- swig wrap definitions (simple swig macros to export functions/classes)
- . . .

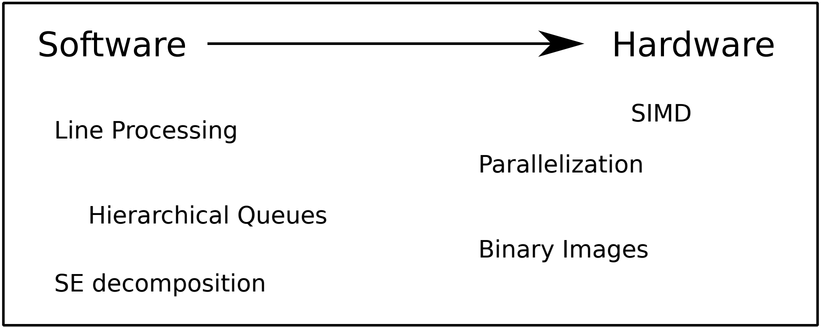
⇒ Most complex/redundant/optimization operations are handled jointly
⇒ Contributors do not need much knowledge to add new features

Example: Dilation function

template<class t>
unaryMorphImageFunction<T, supLine<T> > dilateFunc();

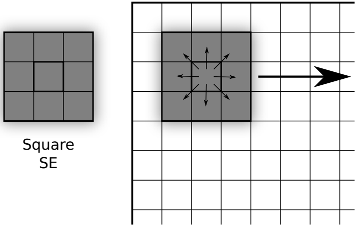
⇒SIMD, Parallelization, specialized SE functions, . . .

Used optimizations



Line processing in morphological operations

The classical approach: Neighborhood iterator

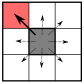


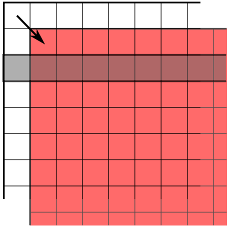
Pseudo-code (dilation):

```
for (j=0;j<height;j++)
  for (i=0;i<width;i++) {
    maxV=0;
    for (it in sePts) {
      outPix(i,j)=MAX(maxV, inPix(i+it.x,
j+it.y));
     }
     outPix(i,j)=maxV;
  }
```

Line processing in morphological operations

The line approach: Using image translations



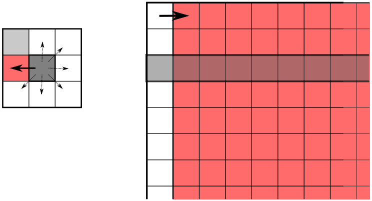


Pseudo-code (dilation):

```
for (j=0;j<height;j++) {
  fill(outLine(j),0);
  for (it in sePts) {
    tmpLine=translate(inLine(j+it.y),it.x);
    for (i=0;i<width;i++) {
      outLine(i)=MAX(outLine(i),tmpLine(i));
    }
  }
```

Line processing in morphological operations

The line approach: Using image translations



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```
for (j=0;j<height;j++) {
  fill(outLine(j),0);
  for (it in sePts) {
    tmpLine=translate(inLine(j+it.y),it.x);
    for (i=0;i<width;i++) {
      outLine(i)=MAX(outLine(i),tmpLine(i));
    }
  }
```

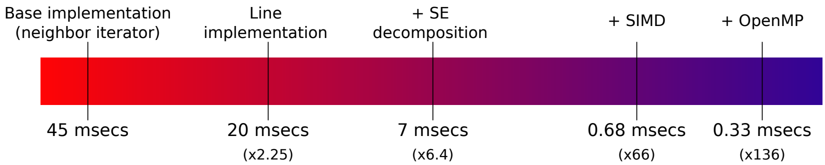
Line processing in morphological operations

Gains

- Speed (>x2)
- Allows some parallelization
- Allows to use SIMD

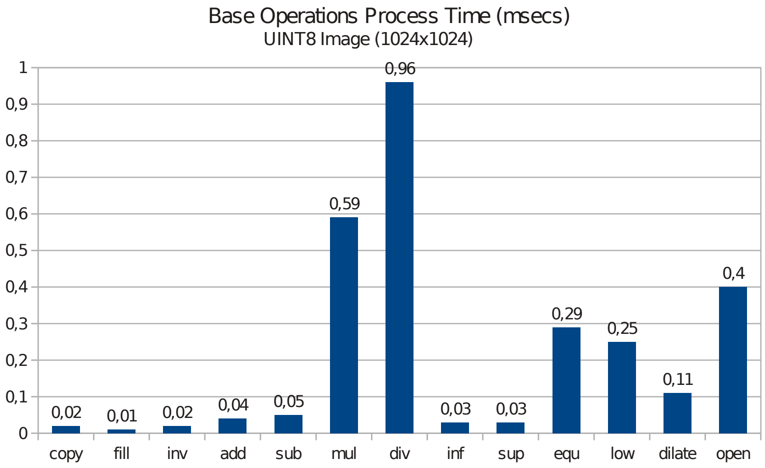
Example function: Morphological Dilation

Morphological dilation on 1024x1024 8bits image using a square structuring element:

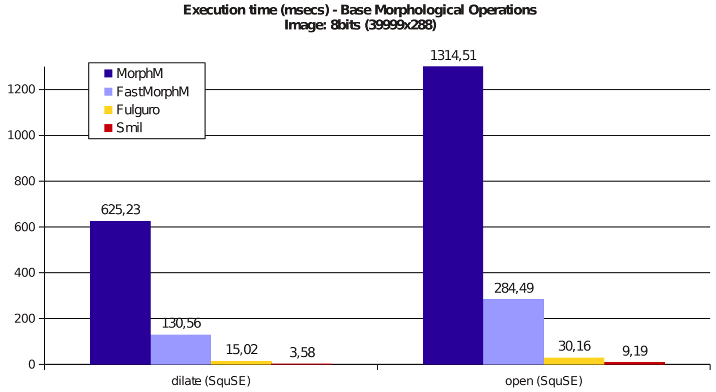


(Intel® Core™ i3 CPU M330 @2.13GHz, 2 cores, 4 threads)

Benchmarks


Base Operations Process Time (msecs)
UINT8 Image (1024x1024)
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0,02
0,01
0,02
0,04
0,05
0,59
0,96
0,03
0,03
0,29
0,25
0,11
0,4
copy
fill
inv
add
sub
mul
div
inf
sup
equ
low
dilate
open

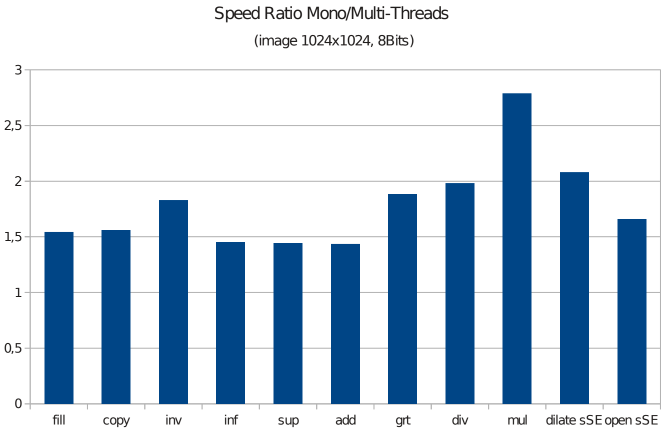
Benchmarks



(Intel® Xeon® CPU E31245 @3,30GHz, 4 cores, 8 threads)

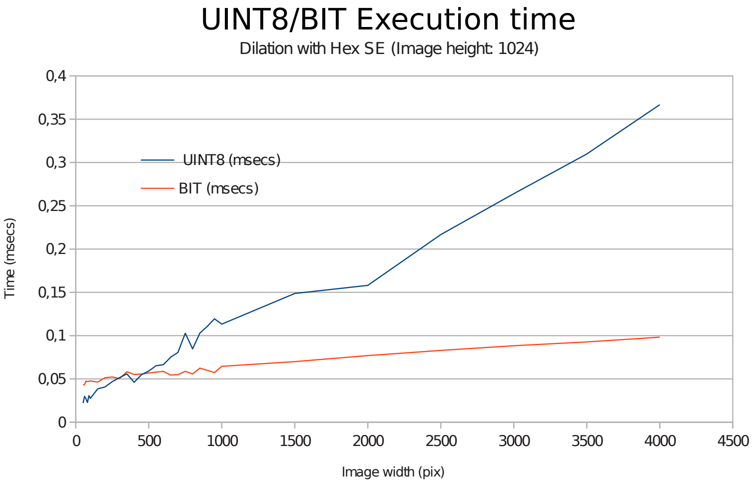
EDIT 30/01/14: the FastMorpM functions used for this graph are ImDilateWithRect and ImOpenWithRect. Using the functions ImDilateWithSquare and ImOpenWithSquare, the actual results for FastMorphM are respectively 5.59 msecs and 11.81 msecs.

Benchmarks



(Intel® Core™ i3 CPU M330 @2.13GHz, 2 cores, 4 threads)

Benchmarks


UINT8/BIT Execution time
Dilation with Hex SE (Image height: 1024)
0,4
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
Time (msecs)
UINT8 (msecs)
BIT (msecs)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Image width (pix)

SLOC

SLOC	Directory	SLOC-by-Language (Sorted)
3440	Morpho	cpp=3440
3107	Base	cpp=2941,python=166
2023	Core	cpp=2023
1551	Gui	cpp=1551
1519	NSTypes	cpp=1519
749	IO	cpp=749
430	doc	python=430
297	CMake	python=297
222	Addons	cpp=222
51	test	cpp=31,java=20
0	top_dir	(none)

Totals grouped by language (dominant language first):

cpp:	12476	(93.18%)
python:	893	(6.67%)
java:	20	(0.15%)

Total Physical Source Lines of Code (SLOC) = 13,389
Development Effort Estimate, Person-Years (Person-Months) = 3.0
(Basic COCOMO model, Person-Months = 2.4 * (KSLOC**1.05))
Schedule Estimate, Years (Months) = 0.82 (9.82)
(Basic COCOMO model, Months = 2.5 * (person-months**0.38))
Estimated Average Number of Developers (Effort/Schedule) = 3.73
Total Estimated Cost to Develop = $ 411,839
(average salary = $56,286/year, overhead = 2.40).
SLOCCount, Copyright (C) 2001-2004 David A. Wheeler

Perspectives

Still much work to be done. . .

- More complex operations optimization:
  - Median, mean, . . .
  - Labellization
  - . . .
- Hierarchical queues optimization:
  - watershed
  - geodesic reconstruction
- GPU ?

Thank you...

SMIL web page:

http://cmm.ensmp.fr/~faessel/smil/

Online WebStart Version (requires Java):

http://cmm.ensmp.fr/~faessel/smil/doc/webstart_page.html