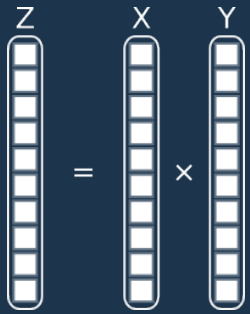
LAPP
Laboratoire d'Annecy de Physique des Particules

Optimisation :
The Hadamard Product

Pierre Aubert

The Hadamard product

$$z_i = x_i \times y_i, \quad \forall i \in 1, N$$




```
for(long unsigned int i(0lu); i < nbElement; ++i){
»       tabResult[i] = tabX[i]*tabY[i];
}
```

Compilation options

https://gcc.gnu.org/onlinedocs/gcc/Optimize-Options.html

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  - Partial function inlining, Assume strict aliasing...

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- **-O3**
  - More function inlining, loop unrolling, partial vectorization...

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  - Try to reduce compilation time, but **-Og** is better for debugging.
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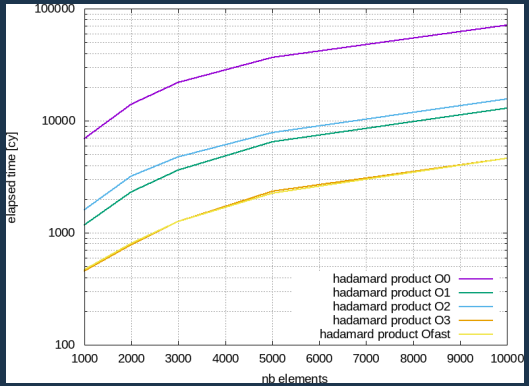
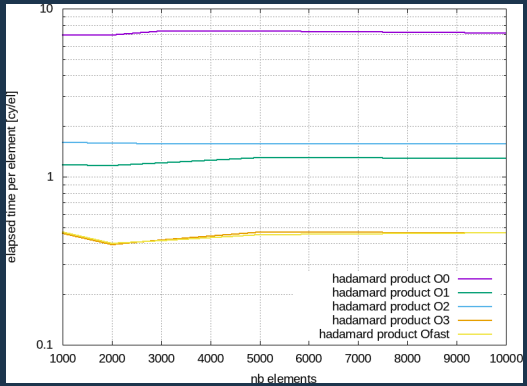
- **-O2**
  - Partial function inlining, Assume strict aliasing...
- **-O3**
  - More function inlining, loop unrolling, partial vectorization...
- **-Ofast**
  - Disregard strict standards compliance. Enable **-ffast-math**, stack size is hardcoded to 32 768 bytes (borrowed from **gfortran**). **Possibly degrades the computation accuracy.**

The Hadamard product : Performance

Total Elapsed Time (cy)



Elapsed Time per element (cy/el)

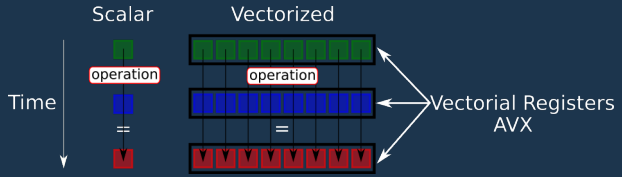


Speed up of **14** between **-O0** and **-O3** or **-Ofast**

What is vectorization ?

The idea is to compute several elements at the same time.

Architecture	Instruction Set	CPU	Nb **float** Computed at the same time
SSE4	2006	2007	4
AVX	2008	2011	8
AVX 512	2013	2016	16



LINUX : **cat /proc/cpuinfo** | **grep avx** MAC : **sysctl -a** | **grep machdep.cpu** | **grep AVX**

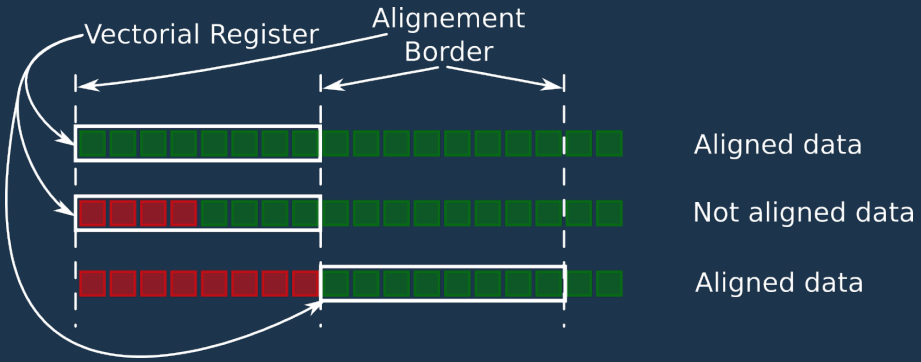
What is vectorization ?

The CPU has to read several elements at the same time.

- Data contiguousness :
  - All the data to be used have to be adjacent with the others.
  - Always the case with pointers but be careful with your applications.

What is vectorization ?

- Data alignement :
  - All the data to be aligned on vectorial registers size.
  - Change **new** or **malloc** to **memalign** or **posix_memalign**



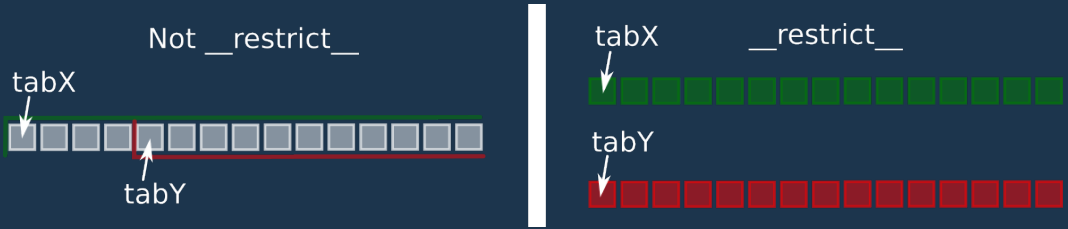
What do we have to do with the code ?

- The __**restrict**__ keyword :
  - Specify to the compiler there is no overhead between pointers

```
float* tabResult,
const float* tabX,
const float* tabY,
```

$\Longrightarrow$

```
float* __restrict__ tabResult,
const float* __restrict__ tabX,
const float* __restrict__ tabY,
```



What do we have to do with the code ?

- The **__builtin_assume_aligned** function :
  - Specify to the compiler pointers are aligned
    - If this is not true, you will get a **Segmentation Fault**.
  - Here **VECTOR_ALIGNEMENT** = 32 (for **float** in **AVX** or **AVX2** extensions).

```
const float* tabX = (const float*)__builtin_assume_aligned(ptabX, VECTOR_ALIGNEMENT);
const float* tabY = (const float*)__builtin_assume_aligned(ptabY, VECTOR_ALIGNEMENT);
float* tabResult = (float*)__builtin_assume_aligned(ptabResult, VECTOR_ALIGNEMENT);
```

Definition in the file **ExampleMinimal/CMakeLists.txt** :

```
set(VECTOR_ALIGNEMENT 32)
add_definitions(-DVECTOR_ALIGNEMENT=${VECTOR_ALIGNEMENT})
```

Compilation Options

- The Compilation Options become :
  - **-O3 -ftree-vectorize -march=native -mtune=native -mavx2**

- **-ftree-vectorize**
  - Activate the vectorization
- **-march=native**
  - Target only the host CPU architecture for binary
- **-mtune=native**
  - Target only the host CPU architecture for optimization
- **-mavx2**
  - Vectorize with AVX2 extention

Modifications Summary

- Data alignement :
  - All the data to be aligned on vectorial registers size.
  - Change **new** or **malloc** to **memalign** or **posix_memalign**

You can use **asterics_malloc** to have LINUX/MAC compatibility (in **evaluateHadamardProduct**):

```
(float*)asterics_malloc(sizeof(float)*nbElement);
```

The __**restrict**__ keyword (arguments of **hadamard_product** function):

```
float* __restrict__ tabResult,
const float* __restrict__ tabX,
const float* __restrict__ tabY,
```

The __**builtin_assume_aligned** function call (in **hadamard_product** function):

```
const float* tabX = (const float*)__builtin_assume_aligned(ptabX, VECTOR_ALIGNEMENT);
const float* tabY = (const float*)__builtin_assume_aligned(ptabY, VECTOR_ALIGNEMENT);
float* tabResult = (float*)__builtin_assume_aligned(ptabResult, VECTOR_ALIGNEMENT);
```

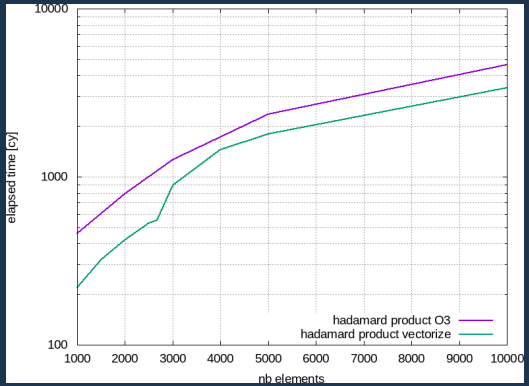
  - The Compilation Options become :
    - **-O3 -ftree-vectorize -march=native -mtune=native -mavx2**

Code Correction

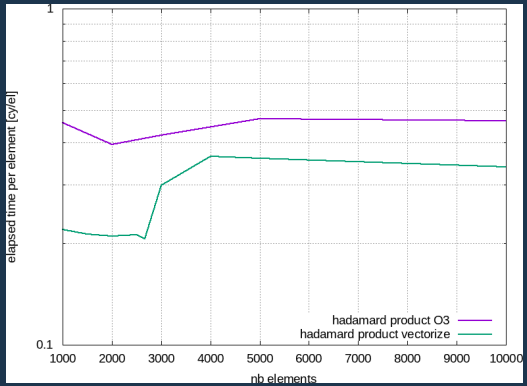
```
void hadamard_product(float* __restrict__ ptabResult, const float* __restrict__ ptabX, const float* __restrict__ ptabY, long unsigned int nbElement){
	const float* tabX = (const float*)__builtin_assume_aligned(ptabX, VECTOR_ALIGNEMENT);
	const float* tabY = (const float*)__builtin_assume_aligned(ptabY, VECTOR_ALIGNEMENT);
	float* tabResult = (float*)__builtin_assume_aligned(ptabResult, VECTOR_ALIGNEMENT);

	for(long unsigned int i(0lu); i < nbElement; ++i){
		tabResult[i] = tabX[i]*tabY[i];
	}
}
```

The Hadamard product : Vectorization

Total Elapsed Time (cy)



Elapsed Time per element (cy/el)

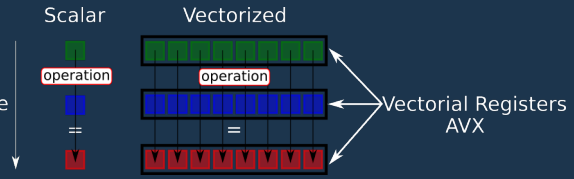


Vectorization by hand : Intrinsic functions

The idea is to force the compiler to do what you want and how you want it.

The Intel intrinsics documentation : `https://software.intel.com/en-us/node/523351`.

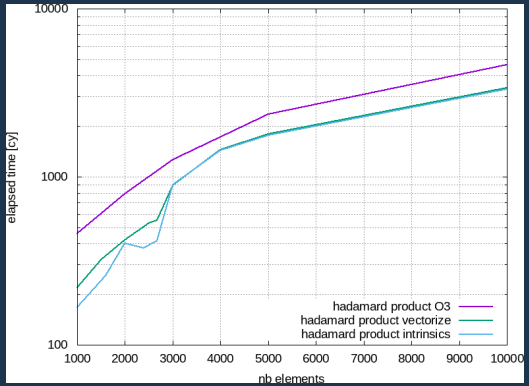
- Some changes (for AVX2):
  - Include : **immintrin.h**
  - **float** $\Longrightarrow$ **__m256** ($= 8$ **float**)
  - Data loading : **_mm256_load_ps**
  - Data Storage : **_mm256_store_ps**
  - Multiply : **_mm256_mul_ps**



Only on aligned data of course.

The Hadamard product : Intrinsics

Total Elapsed Time (cy)



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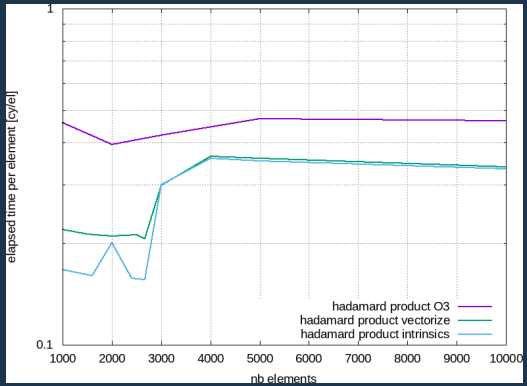
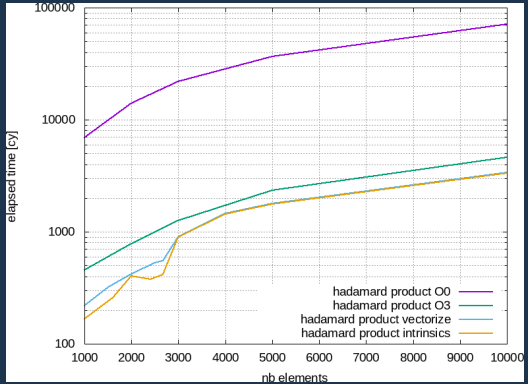


The Hadamard product : Summary

Total Elapsed Time (cy)



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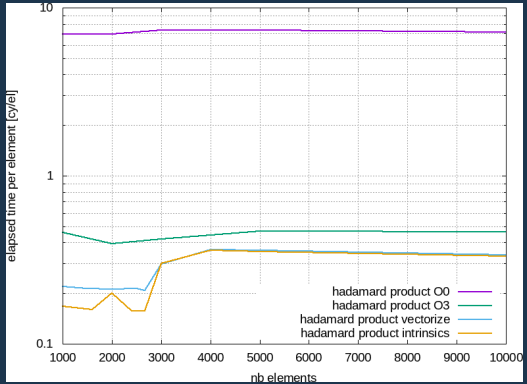

For 1000 elements : intrinsics version is 43.75 times faster than O0
For 1000 elements : intrinsics version is 3.125 times faster than O3
Intrinsics version is a bit faster than vectorized version.

Compiler is very efficient

By the way... what is this step ?

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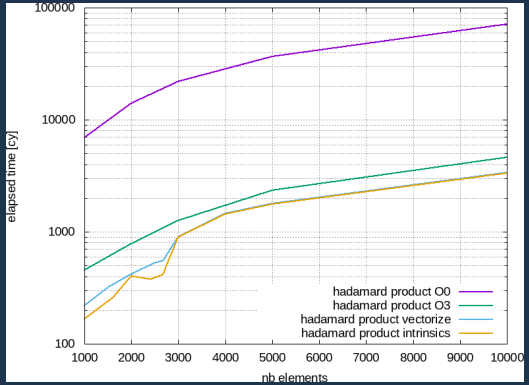

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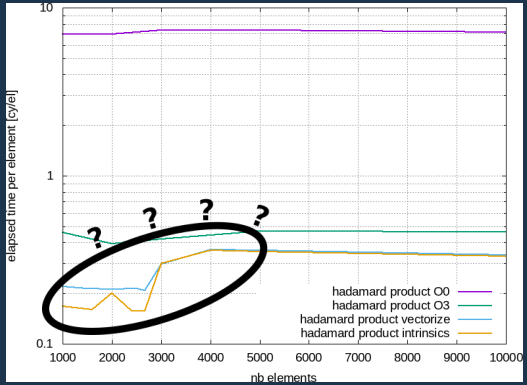

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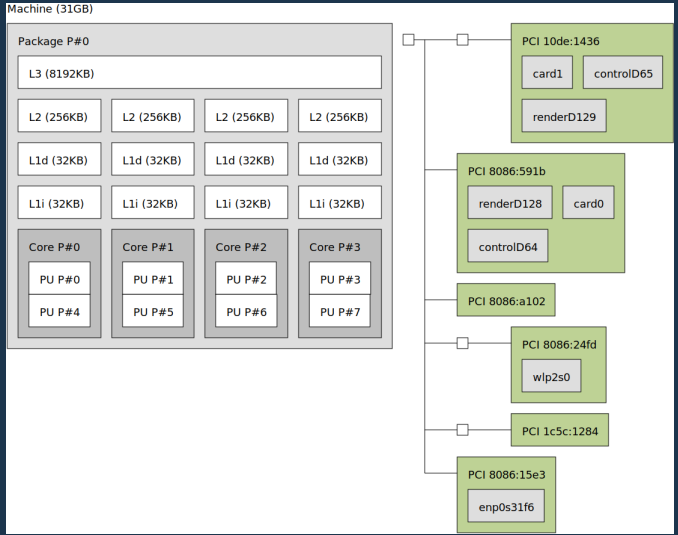
It is due to the Caches !

Let's call **hwloc-ls**



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Let's call **hwloc-ls**

- Time to get a data :
  - **Cache-L1** : 1 cycle
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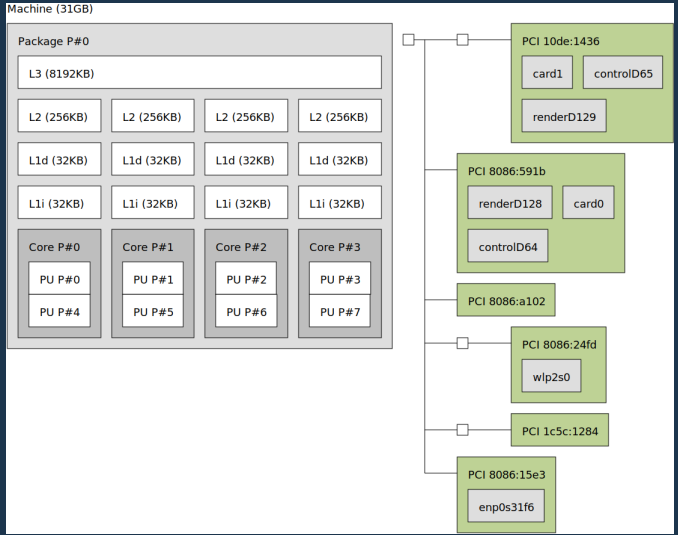
  - **RAM** : 25 cycles



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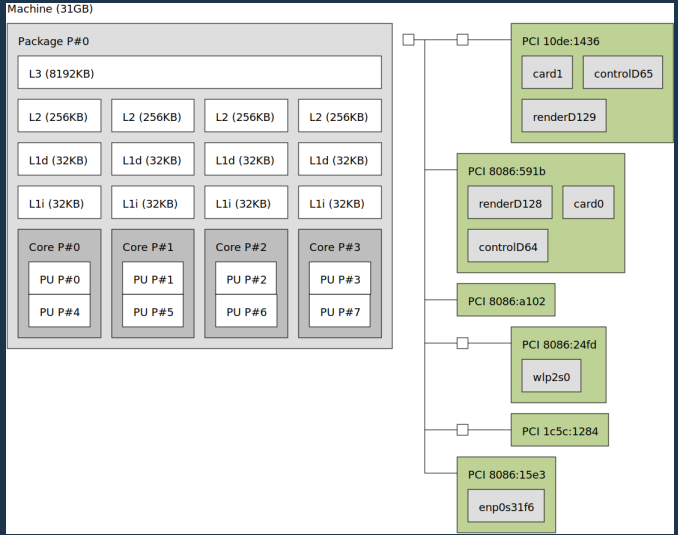
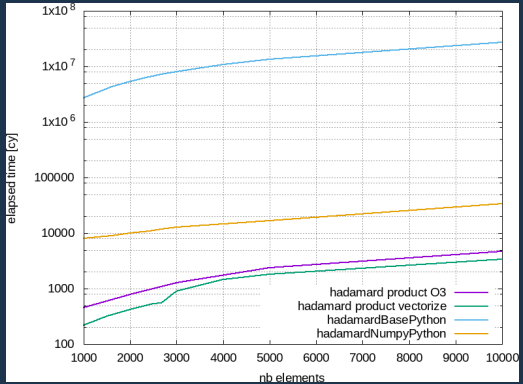
With no cache, 25 cycles to get a data implies a 2.0 *GHz* CPU computes at 80 *MHz* speed.



The Hadamard product : Python

Total Elapsed Time (cy)



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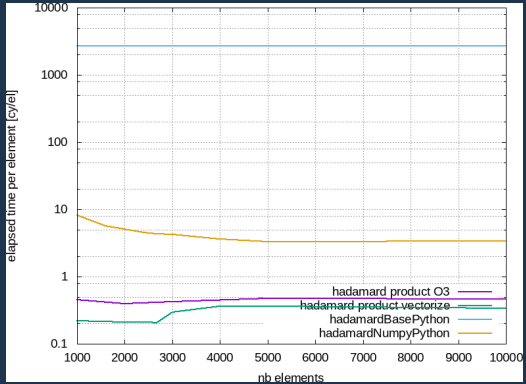
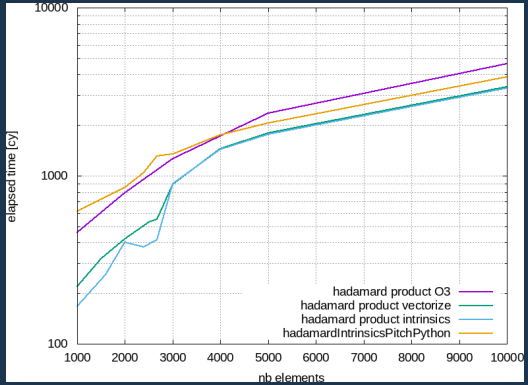


For 1000 elements : vectorized version is 3400 times faster than pure Python !!! (on numpy tables)
For 1000 elements : vectorized version is 8 times faster than numpy version

So, use numpy instead of pure Python (numpy uses the Intel MKL library)

The Python Hadamard product : Summary

Total Elapsed Time (cy)



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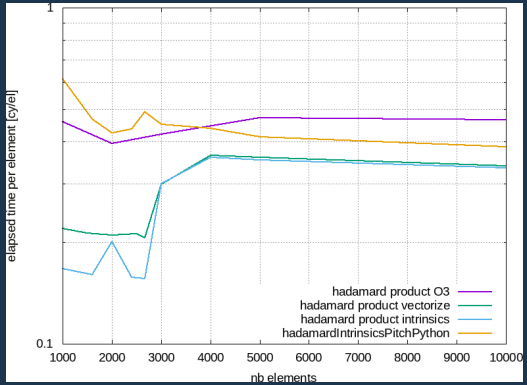


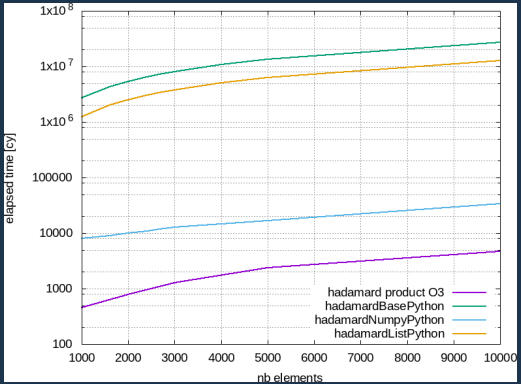
For 1000 elements : intrinsics C++ version is 4 times faster than our Python intrinsics

For 1000 elements : python intrinsics version is 1.2 times faster than O3

The Python function call cost a lot of time

The Python Hadamard product : list

Total Elapsed Time (cy)



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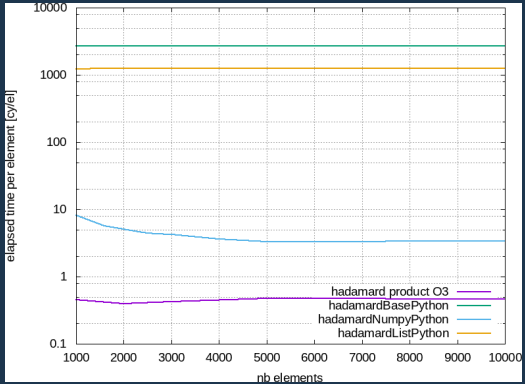

If you want to get elements one per one : lists are faster than **numpy** arrays
If you want to global computation : **numpy** arrays are faster than lists
If you want to be able to wrap you code : use **numpy** arrays

The Python Hadamard product : list

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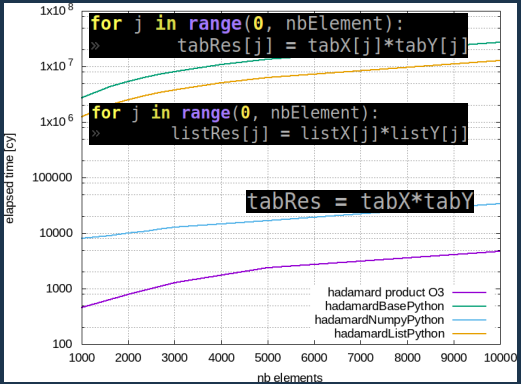
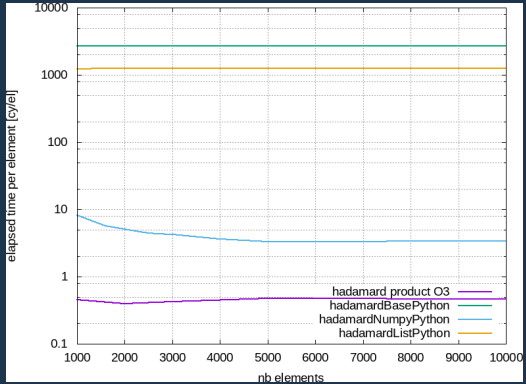


Elapsed Time per element (cy/el)



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