



Introducing SixTrackLib

A Versatile, Hardware-Accelerated Single-Particle Tracking Library

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Introduction

Usage Examples

Design Principles & Implementation

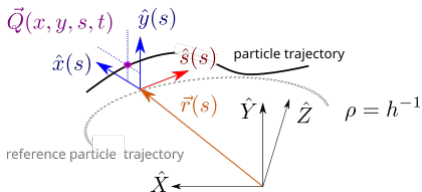
Performance Analysis

Integration Into Python Programs

Conclusion & Outlook

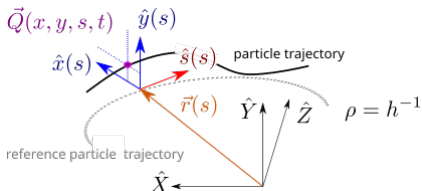
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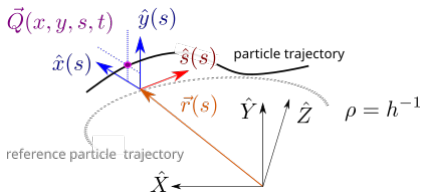
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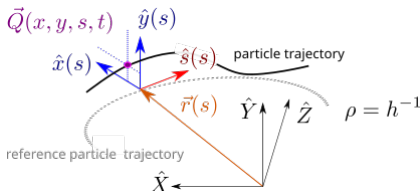
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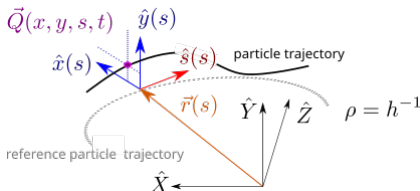
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5. Library: independent of application, low barrier of entry, reusable, embedable, extensible (in contrast to established application SixTrack: <https://github.com/SixTrack/SixTrack>)

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<http://lhathome.web.cern.ch/projects/sixtrack>
- **Across these: same API/syntax**
(i.e. without having to rewrite any user-code)
- **Regular users should not need any GPU/HPC knowledge**
(but allow advanced users to tweak things)

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 - sixtracktools: Access SixTrack IO files from Python
<https://github.com/SixTrack/sixtracktools>

Examples :: Track All Particles Until Turn On CPU

```
In [1]: import sixtracklib as st

# Load particle data and the accelerator machine description from
# a binary dump:

particles = st.ParticlesSet.fromfile("./particles.bin")
lattice = st.Elements.fromfile("./elements.bin")

# Create a track-job instance
job = st.TrackJob( lattice, particles )

# Track all particles until they are in turn 100
job.track_until( 100 )

# Collect the particle state -> not strictly required on the CPU
job.collect_particles()

# particles now contains the updated state after tracking for 100 turns
# ....
```

Examples :: Track All Particles Until Turn On GPU (OpenCL)

```
In [1]: import sixtracklib as st
```

```
# Like before, load particles and machine description from binary dumps
particles = st.ParticlesSet.fromfile( "./particles.bin" )
lattice = st.Elements.fromfile( "./lattice.bin" )

# We want to track now using OpenCL; get a list of supported devices
!clinfo -l
```

```
Platform #0: NVIDIA CUDA
```

```
+-- Device #0: TITAN V
```

```
`-- Device #1: GeForce GT 1030
```

```
Platform #1: Intel(R) CPU Runtime for OpenCL(TM) Applications
```

```
`-- Device #0: AMD Ryzen Threadripper 1950X 16-Core Processor
```

```
Platform #2: AMD Accelerated Parallel Processing
```

```
`-- Device #0: Hawaii
```

```
In [2]: # Initialize the TrackJob to use the NVidia GT 1030 card
```

```
job = st.TrackJob(lattice, particles, device="opencl:0.1")
```

```
job.track_until( 100 )
```

```
# Collect the particles -> now required
```

```
job.collect_particles()
```

Examples :: Lattice from MAD-X Sequence (via pysixtrack)

```
In [1]: from cpyrad.madx import Madx
import sixtracklib as st
import pysixtrack
from scipy.constants import e, m_p, c
import numpy as np

p0c = 6.0 * 1e9 # (P0 * c) [eV]
Etot = np.sqrt( p0c**2 + ( m_p / e )**2 * c**4 ) * 1e-9 # [GeV]

In [2]: mad = Madx()
mad.call(file="fodo.madx")
mad.command.beam(particle='proton',energy=str(Etot))
mad.use(sequence="FODO")

# Setup the lattice from the MAD-X Sequence
sis18 = mad.sequence.FODO
ps_line, _ = pysixtrack.Line.from_madx_sequence(sis18)
elements = st.Elements()
elements.append_line(ps_line)

# Setup the particles consistent with (P0*c)
particles = st.Particles.from_ref(1000, p0c=p0c)

In [3]: # From here on, continue as before
job = st.TrackJob(lattice, particles, device="opencl:0.1")
job.track_until( 100 )
job.collect_particles()
```

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- Design Goal: consistent API across languages & architectures
- Challenge: limit externally facing API surface, stability promises
- \Rightarrow Focus SixTrackLib on tracking
- \Rightarrow Move auxiliary components out of the library

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```
In [1]: import pysixtrack as pyst
        particle_1=pyst.Particles()
        particle_1.x=1
        particle_1.y=1

        particle_2=particle_1.copy()

        belem1=pyst.elements.RFMultipole(knl=[.5,2,.2],ksl=[.5,3,.1])
        belem2=pyst.elements.Multipole(knl=e11.knl,ksl=e11.ksl)

        belem1.track(particle_1)
        belem2.track(particle_2)

        assert particle_1.compare(particle_2,abs_tol=1e-15), "should have same effect!"
```

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```
In [1]: from cobjects import CField, CObject, CBuffer
import numpy as np

class VecObj(CObject):
    _typeid = 1024 # to be coordinated across stored obj
    x = CField(0, 'real', default=1.0, alignment=8) # Scalar
    y = CField(1, 'real', default=0.0, length=4, alignment=8) # Fixed Size Vec
    # z ... dynamically sized vector of 3 * z_length elements
    z_length = CField(2, 'uint64', const=True, alignment=8)
    z = CField(3, 'real', default=0.0, pointer=True, length='3*z_length', alignment=8)

    def __init__(self, z_length=None, **kwargs):
        if z_length is None:
            z_length = 1
        super().__init__(z_length=z_length, **kwargs)
```

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- Allows light-weight, zero-copy, in-place access to stored objects

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```
In [2]: buffer = CBuffer()
        obj1 = VecObj(cbuffer=buffer, z_length=10)
        obj2 = VecObj(cbuffer=buffer)

        assert len(obj1.z) == 30
        assert len(obj2.z) == 3

        alias_to_obj2 = buffer.get_object(1)
        alias_to_obj2.x = 5.0
        assert np.isclose(alias_to_obj2.x, obj2.x, atol=1e-16)
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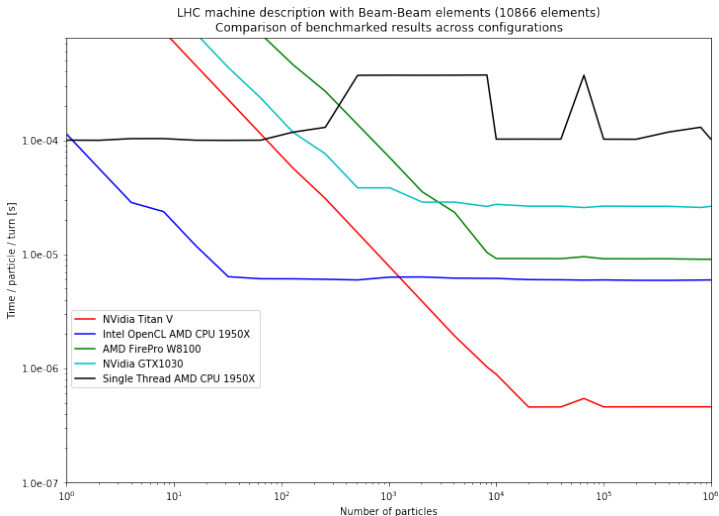
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- Challenge: if a buffer of cobjects is moved, all stored pointers have to be "remapped"
- → cobjects buffers are intended to be used "sequentially"

Performance Analysis :: Full LHC lattice, OpenCL Backend



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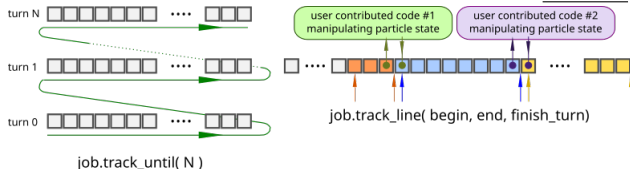
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- Use `track_line()` & manipulate particle state in-place



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Example: Integration of SixTrackLib With PyCUDA

```
In [1]: import sixtracklib as st
import numpy as np
import pycuda
from pycuda import gpuarray, driver, autoinit

particles = st.ParticlesSet.fromfile("./particles.bin")
lattice = st.Elements.fromfile("./lattice.bin")
job = st.CudaTrackJob(lattice, particles)

# Initialize the particles to some values on the host
job.particles_buffer.get_object(0).x[:] = np.array( [-1.0, -2.0 ])

# push particle state to the device
job.push_particles()

In [2]: job.fetch_particle_addresses()
ptr_particles_addr = job.get_particle_addresses(0) #0 .. only one particle set
particles_addr = ptr_particles_addr.contents # particles_addr contains addr *on the device*

print("num_particles = {0:8d}".format(particles_addr.num_particles))
print("x      begin at = {0:16x}".format(particles_addr.x))

num_particles =      2
x      begin at =    7f6ca5000190
```

Example: Integration of SixTrackLib With PyCUDA (cont.)

```
In [3]: # Create a PyCUDA GPUArray coinciding with our memory range
        cuda_x = pycuda.gpuarray.GPUArray(
            particles_addr.num_particles, np.float64, gpudata=particles_addr.x)

        # Modify the values via the cuda_x array
        new_values = np.array( [ 5.0, 6.0 ] )
        cuda_x[:] = new_values

In [4]: # Verify that the particle state has been modified
        job.collect_particles()
        print( job.particles_buffer.get_object(0).x )

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- This way of integration is an additional motivation to support both OpenCL and CUDA!
- But: corresponding integration with PyOpenCL tbd/wip

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- ...
- **Beyond entry-level usage → Platform-level integration!**

Conclusion & Outlook

- Writing a cross-platform, multi-language library that behaves like a proper Python module is challenging
- Approach chosen for SixTrackLib is feasible & performance numbers and feedback from users are encouraging
- Programming to least-common denominator & heavily relying on abstractions has its limitations → Look into reflection & automatic code-generation from pysixtrack
- Goal: Using SixTrackLib as tracking backend to SixTrack and within the context of LHC@Home
- Goal: Simplify installation and deployment for Python users
- Goal: Optimise run-time performance and scalability
- Goal: Continue integration efforts with PyHEADTAIL et al

Thank You For Your Attention!

Backup Slides

Example :: Tracking Map (Drift)

```
SIXTRL_INLINE NS(track_status_t) NS(Track_particle_drift)(
    SIXTRL_PARTICLE_ARGPTR_DEC NS(Particles)* SIXTRL_RESTRICT p,
    NS(particle_num_elements_t) const ii,
    SIXTRL_BE_ARGPTR_DEC const NS(Drift) *const SIXTRL_RESTRICT drift )
{
    typedef NS(particle_real_t) real_t;

    real_t const rpp      = NS(Particles_get_rpp_value)( p, ii );
    real_t const xp       = NS(Particles_get_px_value )( p, ii ) * rpp;
    real_t const yp       = NS(Particles_get_py_value )( p, ii ) * rpp;
    real_t const length    = NS(Drift_get_length)( drift );
    real_t const dzeta     = NS(Particles_get_rvv_value)( p, ii ) -
        ( ( real_t )1 + ( xp*xp + yp*yp ) / ( real_t )2 );

    NS(Particles_add_to_x_value)( p, ii, xp * length );
    NS(Particles_add_to_y_value)( p, ii, yp * length );

    SIXTRL_ASSERT( NS(Particles_get_beta0_value)( p, ii ) > ( real_t )0 );

    NS(Particles_add_to_s_value)( p, ii, length );
    NS(Particles_add_to_zeta_value)( p, ii, length * dzeta );

    return SIXTRL_TRACK_SUCCESS;
}
```

Example :: C++ API Example

```
#include "sixtracklib/sixtracklib.hpp"

int main()
{
    namespace st = sixtrack;

    st::Buffer particle_set( "./particles.bin" );
    st::Buffer lattice( "./lattice.bin" );

    // We have to be explicit about using the CPU for tracking
    st::TrackJobCpu job( particle_set, lattice );

    // Track until turn 100
    job.trackUntil( 100 );

    // Collect the particle state -> would not be needed for the CPU TrackJob
    job.collectParticles();

    // particle_set now contains the tracked data
    // ... Do something with the particles ...

    return 0;
}
```

Example :: C99 API Example

```
#include "sixtracklib/sixtracklib.h"

int main()
{
    NS(Buffer)* particle_set = NS(Buffer_new_from_file)( "./particles.bin" );
    NS(Buffer)* lattice      = NS(Buffer_new_from_file)( "./lattice.bin" );

    /* We have to be explicit about using the CPU for tracking */
    NS(TrackJobCpu)* job = NS(TrackJobCpu_new)( particle_set, lattice );

    /* Track until turn 100 */
    NS(TrackJob_track_until)( job, 100 );

    /* Collect the particle state ->
     * would not be needed for the CPU TrackJob */
    NS(TrackJob_collect_particles)( job );

    /* particle_set now contains the tracked data */
    /* ... Do something with the particles ... */

    /* Cleaning-Up */
    NS(TrackJob_delete)( job );
    NS(Buffer_delete)( particle_set );
    NS(Buffer_delete)( lattice );

    return 0;
}
```