"**Introduction to Multi-physics Simulation with Chrono**"
Tutorial Structure

(1) Monday 1 PM – 5 PM (January 9):

- Overview of the course
- Overview of Chrono
  - Philosophy of Chrono
    - Open source, API driven, Python interface
    - Webpage, information sources, forum
    - Build/test process
  - Chrono foundation modules
  - Supported physics: rigid body dynamics, flexible body dynamics, fluid-solid interaction
- Overview of key C++ features needed to work with Chrono
- Fundamentals of working in GitHub
  - Forking, pull requests, bug/feature requests
- CMake: basic concepts
- Hands-on
  - Getting started with Chrono (configuration, build, running demos)

(2) Tuesday, 8:30 – 12 noon (January 10):

- Theoretical aspects related to the dynamics of systems of rigid bodies
  - Reference frames
  - Generalized coordinates
  - Euler parameters and angular velocities
  - Principle of virtual work
  - Constrained equations of motion
- Modeling MBS in Chrono
  - Rigid bodies and shaft elements
  - Joints
  - Force elements (springs, actuators, motion functions)
  - Validation studies for basic modeling elements
- Visualization
  - Run-time with Irrlicht
  - Run-time with OpenGL
  - Off-line rendering with POVRay
  - Other post-processing support (Gnuplot)
- Hands-on
  - Dynamics simulation of a simple slider crank in Chrono

(3) Tuesday, 1 PM – 5 PM (January 10):

- Handling Frictional Contact in Chrono
  - The complementarity approach, DVI problems
  - The penalty approach, constitutive material laws
- Collision detection in Chrono
  - Contact shapes
  - Geometric information (envelope, margin, radius of curvature)
  - Algorithms: broadphase + narrowphase
  - Bullet and GJK
  - Custom collision detection and contact processing
- Solution methods
  - Implicit integration (HHT)

  - Semi-implicit Euler for (DVI) frictional contact problems
  - Linear solvers
- Hands-on
  - Handling of friction and contact in Chrono: slider crank mechanism, revisited

(4) Wednesday, 8:30 – 12 noon (January 11)

- Aspects of parallel computing relevant in Chrono
  - GPU
  - Multi-core
  - Distributed memory
- Chrono::Parallel and granular dynamics
  - Philosophy of Chrono::Parallel; modeling aspects
  - Parallel collision detection
  - Sampling methods for volume filling
  - Creation of models containing granular material
  - Validation studies
- Python interface for Chrono
  - Demo
- Chrono Interface to SolidWorks
  - Demo
- Support for mechatronics in Chrono
  - Support for modeling robotic systems
  - Bio-inspired robot demo

(5) Wednesday, 1 PM – 5 PM (January 11)

- Chrono::FEA theoretical concepts
  - Overview of ANCF for nonlinear finite element analysis
  - Overview of co-rotational implementation for linear finite element analysis
  - Contact with FEA meshes
    - Point cloud vs. contact surfaces
    - Mesh-rigid and mesh-mesh
  - Overview of validation studies
- Hands on, Chrono::FEA
  - Example with beam elements
    - Constraints between FEA mesh and rigid bodies
    - Enabling contact for FEA meshes
    - Specifying loads
  - Demo w/ ANCF shell

(6) Thursday, 8:30 – 12 noon (January 12)

- Chrono::Vehicle Tutorial
  - Vehicle types and topologies
  - Templated-based design, JSON support
  - Terrain models (Rigid, Soft Contact Model-SCM, FEA)
  - Powertrain models
  - Driver models
  - Chrono::Vehicle visualization
- Hands-on
  - Description of various demos and test programs
  - Extracting output, off-line visualization

(7) Thursday, 1 PM – 5 PM (January 12)

- Chrono::Vehicle Wheeled Vehicles
  - Subsystems
    - Templates and JSON specification
  - Wheeled vehicle demos
- Chrono::Vehicle Tracked Vehicles
  - Subsystems
    - Track assembly
    - Templates and JSON specification
  - Sprocket-track contact
    - Custom collision callbacks
  - Tracked vehicle demos
- Hands-on
  - Specifying a vehicle model through JSON files
  - Creating/modifying JSON specification files

(8) Friday, 8:30 – 12 noon (January 13)

- Chrono::Vehicle Interoperability
  - Chrono::Vehicle + Chrono::Parallel examples
  - Co-simulation support using MPI
  - Demo
- Chrono support for MATLAB/Simulink
  - Demo
- Support for fluid dynamics in Chrono
  - Overview of Smoothed Particle Hydrodynamics
  - Support for Fluid-Solid Interaction support in Chrono
  - Demo
- Features under development
  - Support for sensors
- Feedback, course evaluation, wrap up