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

Day 1

Morning: 8:30am – noon

- Overview of the course (20 minutes)
- Overview of Chrono (30 minutes)
  - 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 (1.5 hour)
- Fundamentals of working in GitHub (20 minutes)
  - Forking, pull requests, bug/feature requests
- CMake: basic concepts (20 minutes)
- Hands on (30 minutes)
  - Getting started with Chrono (configuration, build, running demos)

Lunch: 1 hour

Afternoon: 1:00pm – 5:00pm

- Theoretical aspects related to the dynamics of systems of rigid bodies (1.5 hours)
  - Reference frames
  - Generalized coordinates
  - Euler parameters and angular velocities
  - Principle of virtual work
  - Constrained equations of motion
- Modeling MBS in Chrono (1 hour)
  - Rigid bodies and shaft elements
  - Joints
  - Force elements (springs, actuators, motion functions)
  - Validation studies for basic modeling elements
- Visualization (0.5 hours)
  - Run-time with Irrlicht
  - Run-time with OpenGL
  - Off-line rendering with POVRay
  - Other post-processing support (Gnuplot, Paraview)
- Hands on (1 hour)
  - Dynamics simulation of a simple slider crank in Chrono

Day 2

Morning: 8:30am – noon

- Handling Frictional Contact in Chrono (1.5 hour)
  - The complementarity approach, DVI problems
  - The penalty approach, constitutive material laws
- Collision detection in Chrono (1 hour)
  - Contact shapes
  - Geometric information (envelope, margin, radius of curvature)
  - Algorithms: broadphase + narrowphase
  - Bullet and GJK

    - Custom collision detection and contact processing
- Solution methods (45 mins)
    - Implicit integration (HHT)
    - Semi-implicit Euler for (DVI) frictional contact problems
    - Linear solvers
- Aspects of parallel computing relevant in Chrono (30 mins)
    - GPU
    - Multi-core
    - Distributed memory

Lunch: 1 hour

Afternoon: 1:00pm – 4:30pm
- Chrono::Parallel and granular dynamics (1 hour)
    - Philosophy of Chrono::Parallel; modeling aspects
    - Parallel collision detection
    - Sampling methods for volume filling
    - Creation of models containing granular material
    - Validation studies
- Hands on (2.5 hours)
    - Handling of friction and contact in Chrono: slider crank mechanism, revisited

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Day 3

Morning: 8:30am – noon
- Chrono::FEA theoretical concepts (2 hours)
    - Overview of ANCF
    - Overview of co-rotational implementation
    - Contact with FEA meshes
        - Point cloud vs. contact surfaces
        - Mesh-rigid and mesh-mesh
    - Overview of validation studies
- Hands on, Chrono::FEA (1.5 hours)
    - Example with beam elements
        - Simple example
        - Cables colliding with a rigid obstacle
    - Example with shell elements
        - Simple example

Lunch: 1 hour

Afternoon: 1:00pm – 4:30pm
- Chrono::Vehicle Tutorial (2 hours)
    - 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 (1.5 hours)
    - Description of various demos and test programs
    - Extracting output, off-line visualization

Day 4

Morning: 8:30am – noon

- Chrono::Vehicle Wheeled Vehicles (1.5 hours)
  - Tire models
    - Rigid, LuGre, Fiala, Pacejka
    - FEA (ANCF and co-rotational)
  - Subsystems
    - Templates and JSON specification
  - Simulation samples

- Hands-on wheeled vehicles (2 hours)
  - TBD

Lunch: 60 mins

Afternoon: 1:00pm – 4:30pm

- Chrono::Vehicle Tracked Vehicles (1.5 hours)
  - Subsystems
    - Track assembly
    - Templates and JSON specification
  - Sprocket-track contact
    - Custom collision callbacks
  - Simulation samples

- Hands on tracked vehicles (2 hours)
  - TBD

Day 5

Morning: 8:30am – noon

- Chrono::Vehicle Interoperability (1 hour)
  - Chrono::Vehicle + Chrono::Parallel examples
  - Co-simulation support using MPI
- Other Chrono features (0.5 hours)
  - Interfacing to MATLAB/Simulink
  - Interface to SolidWorks
- Support for fluid dynamics and MPM in Chrono (1 hour)
  - Overview of Smoothed Particle Hydrodynamics
  - Support for Fluid-Solid Interaction support in Chrono
  - Validation studies
  - Material Point Method Support
- Chrono, looking ahead (0.5 hours)
  - Autonomous vehicle support
  - Ogre transition
- Feedback, course evaluation, wrap up (0.5 hours)

Lunch: 60 mins

Afternoon: 1:00pm – 4:30pm

- No afternoon session