Chrono::Vehicle Tutorial
Tracked vehicle system
Data flow

1. **DRIVER**
   - Throttle input
2. **POWERTRAIN**
   - Driveshaft torque
   - Driveshaft speed
3. **VEHICLE**
   - Steering input
   - Braking input
   - Track shoe states
4. **TERRAIN**
   - Forces and moments on track shoe bodies
Vehicle ISO reference frames

(XYZ) – vehicle (chassis) reference frame
(XYZ) – chassis COM reference frame
(XYZ) – right sprocket reference frame
ChTrackedVehicle base class

• A ChTrackedVehicle is a Chrono ChVehicle:

```cpp
/// Base class for chrono tracked vehicle systems.
/// This class provides the interface between the vehicle system and other
/// systems (terrain, driver, etc.)
class CH_VEHICLE_API ChWheeledVehicle : public ChVehicle
```

• A ChTrackedVehicle has:

```cpp
std::shared_ptr<ChTrackAssembly> m_tracks[2]; ///< handles to the track assemblies (left/right)
std::shared_ptr<ChTrackDriveline> m_driveline; ///< handle to the driveline subsystem
ChTrackContactManager* m_contacts; ///< manager for internal contacts
```
ChTrackedVehicle base class accessors

• Deferring to its constituent subsystems as needed, a ChTrackedVehicle provides accessors for:
  • Vehicle subsystems
  • States of the vehicle’s track shoe bodies
  • Inherited accessors from ChVehicle

• A ChTrackedVehicle intermediates communication between other systems (e.g., powertrain, driver, etc.) and constituent subsystems (e.g., sprockets, driveline, brakes, etc.)
ChTrackedVehicle base class virtual functions

- Synchronize the vehicle at a communication time with data from other systems

```cpp
/// Update the state of this vehicle at the current time.
/// The vehicle system is provided the current driver inputs (throttle between
/// 0 and 1, steering between -1 and +1, braking between 0 and 1), the torque
/// from the powertrain, and tire forces (expressed in the global reference
/// frame).
void Synchronize(double time,
                 double steering,  /// [in] current steering input [-1,+1]
                 double braking,   /// [in] current braking input [0,1]
                 double powertrain_torque,  /// [in] input torque from powertrain
                 const TrackShoeForces& shoe_forces_left,  /// [in] vector of track shoe forces (left side)
                 const TrackShoeForces& shoe_forces_right);  /// [in] vector of track shoe forces (left side)
```
Data exchange structures

- TrackShoeForce structure – encapsulates external forces applied to a track shoe body
  - Force vector and application point (expressed in the global reference frame)
  - Moment vector (expressed in the global reference frame)
- A track shoe force structure can be specified for any (or all) track shoes (e.g., to model track-terrain contact forces)
  - The force and moment are applied to the track shoe body as external forces

```c++
/// Structure to communicate a set of generalized track shoe forces.
struct TrackShoeForce {
    ChVector<> force;  ///< force vector, expressed in the global frame
    ChVector<> point;  ///< global location of the force application point
    ChVector<> moment; ///< moment vector, expressed in the global frame
};
```
JSON specification file for a tracked vehicle

```json
{
  "Name": "M113 vehicle",
  "Type": "Vehicle",
  "Template": "TrackedVehicle",

  "Chassis":
  {
    "Input File": "M113/chassis/M113_Chassis.json"
  },

  "Track Assemblies":
  [
    {
      "Input File": "M113/track_assembly/M113_TrackAssemblySinglePin_Left.json",
      "Offset": 1.0795
    },
    {
      "Input File": "M113/track_assembly/M113_TrackAssemblySinglePin_Right.json",
      "Offset": -1.0795
    }
  ],

  "Driveline":
  {
    "Input File": "M113/driveline/M113_SimpleTrackDriveline.json"
  }
}
```
Tracked vehicle subsystem hierarchy

- Tracked vehicle
  - Chassis
    - Sprocket
  - Left track assembly
  - Right track assembly
    - Idler (with tensioner)
  - Driveline
    - Suspension (road-wheel assembly)
      - Track-shoe
        - Road-wheel
  - Driveline
Subsystem dependencies

• **Sprocket ↔ track-shoe**
  - Sprocket type and track-shoe type must match:
    - “single-pin”
    - “double-pin”
  - Contact between sprocket and track shoes is implemented through a custom callback which assumes consistency

• **Sprocket/Idler/road-wheel ↔ track-shoe**
  - Wheel type and track-shoe type must match:
    - “single-wheel” and “lateral guiding pin”
    - “double-wheel” and “central guiding pin”
  - Note: track shoes with lateral guiding pins currently not implemented
Track Assembly Subsystem
ChTrackAssembly base class

- ChTrackAssembly is a composite class, used to manage all subsystems comprising a (left or right) track assembly:
  - A sprocket and brake
  - An idler assembly (idler wheel + tensioner mechanism)
  - A set of suspensions (each containing a road-wheel)
  - A set of track shoes
- Derived classes ensure consistency between subsystem types
- ChTrackAssembly provides the algorithm for assembling the track shoes around the wheels (sprocket, idler, road-wheels)

```cpp
/// Definition of a track assembly.
/// A track assembly consists of a sprocket, an idler (with tensioner mechanism),
/// a set of suspensions (road-wheel assemblies), and a collection of track shoes.
class CH_VEHICLE_API ChTrackAssembly : public ChPart
```
ChTrackAssembly class members

• A ChTrackAssembly has:

```cpp
VehicleSide m_side;       // assembly on left/right vehicle side
std::shared_ptr<ChIdler> m_idler; // idler (and tensioner) subsystem
std::shared_ptr<ChTrackBrake> m_brake; // sprocket brake
ChRoadWheelAssemblyList m_suspensions;  // road-wheel assemblies
```

• Derived classes (track assembly templates) manage the sprocket and track shoes of appropriate types
ChTrackAssembly base class accessors

- A ChTrackAssembly provides access to:
  - Its constituent subsystems (sprocket, brake, idler, suspensions, individual track shoes)
    - Sprocket and track shoe access provided through pure virtual methods
  - Relative positions of its constituent subsystems
    - The ISO track assembly reference frame is assumed to have origin at the center of the sprocket
  - Complete state of a track shoe subsystem (through its index in the vector of track shoes in the assembly)
  - Cumulative mass of the track assembly
ChTrackAssembly base class methods

- A ChTrackAssembly provides methods to:

```cpp
/// Initialize this track assembly subsystem.
/// The subsystem is initialized by attaching it to the specified chassis body
/// at the specified location (with respect to and expressed in the reference
/// frame of the chassis). It is assumed that the track assembly reference frame
/// is always aligned with the chassis reference frame.
void Initialize(std::shared_ptr<ChBodyAuxRef> chassis,  ///< [in] handle to the chassis body
    const ChVector<>& location);  ///< [in] location relative to the chassis frame

/// Update the state of this track assembly at the current time.
void Synchronize(double time,  ///< [in] current time
    double braking,  ///< [in] braking driver input
    const TrackShoeForces& shoe_forces);  ///< [in] vector of tire force structures
```
ChTrackAssembly base class virtual methods

• A derived class must provide a method for assembling track shoes around the assembly’s wheels

```cpp
/// Assemble track shoes over wheels.
/// Return true if the track shoes were initialized in a counter clockwise
/// direction and false otherwise.
virtual bool Assemble(std::shared_ptr<ChBodyAuxRef> chassis) = 0;
```

• Track shoes are positioned from below the sprocket, clockwise or counter-clockwise, depending on whether the assembly has a front or rear sprocket

• Note that this process is relatively fragile
  • May require adjustments to initial idler position
Track Assembly Templates

Single-pin
JSON specification for single-pin track assembly (1/2)

```
{
    "Name": "M113 SinglePin TrackAssembly Left",
    "Type": "TrackAssembly",
    "Template": "TrackAssemblySinglePin",
    "Sprocket": {
        "Input File": "M113/sprocket/M113_SprocketSinglePin_Left.json",
        "Location": [0, 0, 0]
    },
    "Brake": {
        "Input File": "M113/brake/M113_TrackBrakeSimple.json"
    },
    "Idler": {
        "Input File": "M113/idler/M113_DoubleIdler_Left.json",
        "Location": [-3.83, 0, -0.12]
    },
    "Track Shoes": {
        "Input File": "M113/track_shoe/M113_TrackShoeSinglePin.json",
        "Number Shoes": 63
    }
}
```
**JSON specification for single-pin track assembly (2/2)**

```
"Suspension Subsystems":
[
    {
        "Input File": "M113/suspension/M113_LinearDamperSuspension_Left.json",
        "Has Shock": true,
        "Location": [-0.655, 0, -0.215]
    },
    {
        "Input File": "M113/suspension/M113_LinearDamperSuspension_Left.json",
        "Has Shock": true,
        "Location": [-1.322, 0, -0.215]
    },
    {
        "Input File": "M113/suspension/M113_LinearDamperSuspension_Left.json",
        "Has Shock": false,
        "Location": [-1.989, 0, -0.215]
    },
    {
        "Input File": "M113/suspension/M113_LinearDamperSuspension_Left.json",
        "Has Shock": false,
        "Location": [-2.656, 0, -0.215]
    },
    {
        "Input File": "M113/suspension/M113_LinearDamperSuspension_Left.json",
        "Has Shock": true,
        "Location": [-3.322, 0, -0.215]
    }
]
```

Location of first (front) suspension subsystem with respect to assembly reference frame.
Track Assembly Templates

Double-pin
JSON specification for double-pin track assembly (1/2)

```json
{
   "Name": "M113 DoublePin TrackAssembly Left",
   "Type": "TrackAssembly",
   "Template": "TrackAssemblyDoublePin",
   "Sprocket": {
      "Input File": "M113/sprocket/M113_SprocketDoublePin_Left.json",
      "Location": [0, 0, 0]
   },
   "Brake": {
      "Input File": "M113/brake/M113_TrackBrakeSimple.json"
   },
   "Idler": {
      "Input File": "M113/idler/M113_DoubleIdler_Left.json",
      "Location": [-3.83, 0, -0.12]
   },
   "Track Shoes": {
      "Input File": "M113/track_shoe/M113_TrackShoeDoublePin.json",
      "Number Shoes": 63
   }
}
```
"Suspension Subsystems":
[
    {
        "Input File": "M113/suspension/M113_LinearDamperSuspension_Left.json",
        "Has Shock": true,
        "Location": [-0.655, 0, -0.215]
    },
    {
        "Input File": "M113/suspension/M113_LinearDamperSuspension_Left.json",
        "Has Shock": true,
        "Location": [-1.322, 0, -0.215]
    },
    {
        "Input File": "M113/suspension/M113_LinearDamperSuspension_Left.json",
        "Has Shock": false,
        "Location": [-1.989, 0, -0.215]
    },
    {
        "Input File": "M113/suspension/M113_LinearDamperSuspension_Left.json",
        "Has Shock": false,
        "Location": [-2.656, 0, -0.215]
    },
    {
        "Input File": "M113/suspension/M113_LinearDamperSuspension_Left.json",
        "Has Shock": true,
        "Location": [-3.322, 0, -0.215]
    }
]
Suspension Subsystem
ChRoadWheelAssembly base class

- Base class for track suspension subsystems
- Provides access to the underlying road-wheel subsystem and its components (body and revolute joint)

```cpp
/// Base class for tracked vehicle suspension (road-wheel assembly) subsystem.
class CH_VEHICLE_API ChRoadWheelAssembly : public ChPart
```
ChRoadWheelAssembly class members

• A ChRoadWheelAssembly has:

```cpp
GuidePinType m_type;  ///< type of the track shoe matching this road wheel
std::shared_ptr<ChRoadWheel> m_road_wheel;  ///< road-wheel subsystem
```
Suspension Templates
Linear-damper suspension
Template specification

Components

- Road-wheel
- Linear damper
- Revolute joint (arm-chassis) with rotational spring
- Suspension arm
- Revolute joint (arm-wheel)

Hard points

- Arm COM

z
y
x
JSON specification for linear-damper suspension

```json
{
   "Name": "M113 Linear Damper Suspension Left",
   "Type": "RoadWheelAssembly",
   "Template": "LinearDamperRWAssembly",

   "Suspension Arm": {
      "Mass": 75.26,
      "COM": [0.144, -0.12, 0.067],
      "Inertia": [0.37, 0.77, 0.77],
      "Location Chassis": [0.288, -0.12, 0.134],
      "Location Wheel": [0, -0.12, 0],
      "Radius": 0.03
   },

   "Torsional Spring": {
      "Spring Constant": 2.5e4,
      "Damping Coefficient": 5e2,
      "Preload": -1e4
   },

   "Damper": {
      "Location Chassis": [-0.3, -0.12, 0.3],
      "Location Arm": [0.184, -0.12, -0.106],
      "Damping Coefficient": 1e2
   },

   "Road Wheel Input File": "M113/road_wheel/M113_DoubleRoadWheel_Left.json"
}
```
Suspension Templates
Rotational-damper suspension
Template specification

- Road-wheel
- Revolute joint (arm-chassis) with rotational spring
- Rotational damper
- Suspension arm
- Revolute joint (arm-wheel)
- Components
- Hard points
- Arm COM
Suspension Templates

Hydropneumatic suspension
Template specification

\[ \xi(\theta) = \sqrt{l^2 - [r \sin(\theta - \alpha) - d]^2} - r \cos(\theta - \alpha) \]

\[ \theta^* = \alpha - \arctan \left( \frac{d}{l - r} \right) \]

Note: WIP
Road-wheel Subsystem
ChRoadWheel base class

- A road wheel is a single rigid body with contact shape specified by a concrete subsystem template class

```cpp
/// Base class for a road wheel subsystem.
class CH_VEHICLE_API ChRoadWheel : public ChPart
```

- Member variables

```cpp
std::shared_ptr<ChBody> m_wheel; ///< handle to the road wheel body
std::shared_ptr<ChLinkLockRevolute> m_revolute;  ///< handle to wheel revolute joint

float m_friction;  ///< contact coefficient of friction
float m_restitution;  ///< contact coefficient of restitution
float m_young_modulus;  ///< contact material Young modulus
float m_poisson_ratio;  ///< contact material Poisson ratio
float m_kn;  ///< normal contact stiffness
float m_gn;  ///< normal contact damping
float m_kt;  ///< tangential contact stiffness
float m_gt;  ///< tangential contact damping
```
ChRoadWheel class members

- A ChRoadWheel has:

```cpp
std::shared_ptr<ChBody> m_wheel;     ///< handle to the road wheel body
std::shared_ptr<ChLinkLockRevolute> m_revolute; ///< handle to wheel revolute joint

float m_friction;  ///< contact coefficient of friction
float m_restitution; ///< contact coefficient of restitution
float m_young_modulus; ///< contact material Young modulus
float m_poisson_ratio; ///< contact material Poisson ratio
float m_kn;        ///< normal contact stiffness
float m_gn;        ///< normal contact damping
float m_kt;        ///< tangential contact stiffness
float m_gt;        ///< tangential contact damping
```
ChRoadWheel base class accessor methods

```cpp
/// Get a handle to the road wheel body.
std::shared_ptr<ChBody> GetWheelBody() const { return m_wheel; }

/// Get a handle to the revolute joint.
std::shared_ptr<ChLinkLockRevolute> GetRevolute() const { return m_revolute; }

/// Return the mass of the road wheel body.
virtual double GetWheelMass() const = 0;

/// Return the moments of inertia of the road wheel body.
virtual const ChVector<>& GetWheelInertia() = 0;

/// Get the radius of the road wheel.
virtual double GetWheelRadius() const = 0;

/// Get coefficient of friction for contact material.
float GetCoefficientFriction() const { return m_friction; }
/// Get coefficient of restitution for contact material.
float GetCoefficientRestitution() const { return m_restitution; }
/// Get Young's modulus of elasticity for contact material.
float GetYoungModulus() const { return m_young_modulus; }
/// Get Poisson ratio for contact material.
float GetPoissonRatio() const { return m_poisson_ratio; }
/// Get normal stiffness coefficient for contact material.
float GetKn() const { return m_kn; }
/// Get tangential stiffness coefficient for contact material.
float GetKt() const { return m_kt; }
/// Get normal viscous damping coefficient for contact material.
float GetGn() const { return m_gn; }
/// Get tangential viscous damping coefficient for contact material.
float GetGt() const { return m_gt; }
```
ChRoadWheel base class methods

/// Set coefficient of friction.
/// The default value is 0.7
void SetContactFrictionCoefficient(float friction_coefficient) { m_friction = friction_coefficient; }

/// Set coefficient of restitution.
/// The default value is 0.1
void SetContactRestitutionCoefficient(float restitution_coefficient) { m_restitution = restitution_coefficient; }

/// Set contact material properties.
/// These values are used to calculate contact material coefficients (if the containing
/// system is so configured and if the DEM-P contact method is being used).
/// The default values are: Y = 1e8 and nu = 0.3
void SetContactMaterialProperties(float young_modulus, ///< [in] Young's modulus of elasticity
        float poisson_ratio  ///< [in] Poisson ratio
    );

/// Set contact material coefficients.
/// These values are used directly to compute contact forces (if the containing system
/// is so configured and if the DEM-P contact method is being used).
/// The default values are: kn=2e5, gn=40, kt=2e5, gt=20
void SetContactMaterialCoefficients(float kn, ///< [in] normal contact stiffness
        float gn, ///< [in] normal contact damping
        float kt, ///< [in] tangential contact stiffness
        float gt ///< [in] tangential contact damping
    );

/// Initialize this road wheel subsystem.
/// The road wheel subsystem is initialized by attaching it to the specified
/// carrier body at the specified location (with respect to and expressed in the
/// reference frame of the chassis).
/// A derived road wheel subsystem template class must extend this default
/// implementation and specify contact geometry for the road wheel.
virtual void Initialize(std::shared_ptr<ChBodyAuxRef> chassis, ///< [in] handle to the chassis body
        std::shared_ptr<ChBody> carrier, ///< [in] handle to the carrier body
        const ChVector<>& location ///< [in] location relative to the chassis frame
    );
Road-wheel Templates

Double road-wheel
ChDoubleRoadWheel geometry

gap

width

radius
JSON specification for double road-wheel

```json
{
    "Name": "M113 Double RoadWheel Left",
    "Type": "RoadWheel",
    "Template": "DoubleRoadWheel",
    "Wheel": {
        "Radius": 0.305,
        "Width": 0.181,
        "Gap": 0.051,
        "Mass": 561.1,
        "Inertia": [19.82, 26.06, 19.82]
    },
    "Contact Material": {
        "Coefficient of Friction": 0.7,
        "Coefficient of Restitution": 0.1,
        "Properties": {
            "Young Modulus": 1e7,
            "Poisson Ratio": 0.3
        },
        "Coefficients": {
            "Normal Stiffness": 2e5,
            "Normal Damping": 40.0,
            "Tangential Stiffness": 2e5,
            "Tangential Damping": 20.0
        }
    },
    "Visualization": {
        "Mesh Filename": "M113/Roller_L.obj",
        "Mesh Name": "Roller_L_POV_geom"
    }
}
```
Sprocket Subsystem
ChSprocket base class

• A sprocket is responsible for collision detection and contact processing between the sprocket and the track shoes

• A derived class which implements a particular sprocket template must specify the custom collision callback object and provide the gear profile as a 2D path.

• The gear profile, a ChLinePath geometric object, is made up of an arbitrary number of sub-paths of type ChLineArc or ChLineSegment sub-lines.

• These must be added in clockwise order, and the end of sub-path i must be coincident with beginning of sub-path i+1.

```cpp
/// Base class for a tracked vehicle sprocket.
/// A sprocket is responsible for contact processing with the track shoes of the containing track assembly.
class CH_VEHICLE_API ChSprocket : public ChPart
```
ChSprocket class members

• A ChSprocket has:

```cpp
std::shared_ptr<ChBody> m_gear;///< handle to the sprocket gear body
std::shared_ptr<ChShaft> m_axle;///< handle to gear shafts
std::shared_ptr<ChShaftsBody> m_axle_to_spindle;///< handle to gear-shaft connector
std::shared_ptr<ChLinkLockRevolute> m_revolute;///< handle to sprocket revolute joint

ChSystem::ChCustomComputeCollisionCallback* m_callback;///< custom collision functor object

float m_friction;///< contact coefficient of friction
float m_restitution;///< contact coefficient of restitution
float m_young_modulus;///< contact material Young modulus
float m_poisson_ratio;///< contact material Poisson ratio
float m_kn;///< normal contact stiffness
float m_gn;///< normal contact damping
float m_kt;///< tangential contact stiffness
float m_gt;///< tangential contact damping
```
Sprocket Templates

Single-pin sprocket
ChSprocketSinglePin geometry

arc radius

outer radius

centers radius
JSON specification for single-pin sprocket (1/2)

```json
{
    "Name": "M113 SinglePin Sprocket Left",
    "Type": "Sprocket",
    "Template": "SprocketSinglePin",
    "Number Teeth": 10,
    "Gear Mass": 436.7,
    "Gear Inertia": [12.22, 13.87, 12.22],
    "Axle Inertia": 1.0,
    "Gear Separation": 0.225,

    "Profile":
    {
        "Addenum Radius": 0.2605,
        "Arc Radius": 0.089,
        "Arc Centers Radius": 0.3,
        "Assembly Radius": 0.245
    }
}
```
JSON specification for single-pin sprocket (2/2)

```
"Contact Material":
{
  "Coefficient of Friction": 0.4,
  "Coefficient of Restitution": 0.1,

  "Properties": {
    "Young Modulus": 1e7,
    "Poisson Ratio": 0.3
  },

  "Coefficients": {
    "Normal Stiffness": 2e5,
    "Normal Damping": 40.0,
    "Tangential Stiffness": 2e5,
    "Tangential Damping": 20.0
  }
},

"Visualization":
{
  "Mesh Filename": "M113/Sprocket_L.obj",
  "Mesh Name": "Sprocket_L_POV_geom"
}
```
Sprocket Templates

Double-pin sprocket
ChSprocketDoublePin geometry
JSON specification for double-pin sprocket (1/2)

```json
{
  "Name": "M113 DoublePin Sprocket Left",
  "Type": "Sprocket",
  "Template": "SprocketDoublePin",
  "Number Teeth": 10,
  "Gear Mass": 436.7,
  "Gear Inertia": [12.22, 13.87, 12.22],
  "Axle Inertia": 1.0,
  "Gear Separation": 0.225,
  "Profile": {
    "Addenum Radius": 0.2715,
    "Arc Radius": 0.0223,
    "Assembly Radius": 0.242,
    "Arc Center Height": 0.2371,
    "Arc Center Offset": 0.0464
  }
}
```
"Contact Material":
{
   "Coefficient of Friction": 0.4,
   "Coefficient of Restitution": 0.1,

   "Properties": {
      "Young Modulus": 1e7,
      "Poisson Ratio": 0.3
   },

   "Coefficients": {
      "Normal Stiffness": 2e5,
      "Normal Damping": 40.0,
      "Tangential Stiffness": 2e5,
      "Tangential Damping": 20.0
   }
}
}
Track-shoe Subsystem
ChTrackShoe base class

- Specifies the interface for the track shoe subsystem
- Provides the contact material properties
- A derived class must implement:
  - a method to initialize the track shoe subsystem at a given location and with a given orientation
  - a method to connect two adjacent track shoes (always assumed to have proper relative positions)

// Base class for a track shoe.
class CH_VEHICLE_API ChTrackShoe : public ChPart
ChTrackShoe class members

• A ChTrackShoe has:

```cpp
size_t m_index;          ///< index of this track shoe within its containing track assembly
std::shared_ptr<ChBody> m_shoe;  ///< handle to the shoe body

float m_friction;        ///< contact coefficient of friction
float m_restitution;     ///< contact coefficient of restitution
float m_young_modulus;   ///< contact material Young modulus
float m_poisson_ratio;   ///< contact material Poisson ratio
float m_kn;              ///< normal contact stiffness
float m_gn;              ///< normal contact damping
float m_kt;              ///< tangential contact stiffness
float m_gt;              ///< tangential contact damping
```
Track-shoe Templates

Single-pin track-shoe
ChTrackShoeSinglePin geometry

- Single-pin, single-body track shoe
- Central guiding pin (i.e. consistent with ChDoubleIdler, ChDoubleRoadWheel)
- Connection to adjacent track shoe is through revolute joints (except the track loop closure)
JSON specification for single-pin track-shoe (1/2)

```json
{
    "Name": "M113 SinglePin TrackShoe Left",
    "Type": "TrackShoe",
    "Template": "TrackShoeSinglePin",

    "Shoe": {
        "Height": 0.06,
        "Pitch": 0.154,
        "Mass": 18.02,
        "Inertia": [0.22, 0.04, 0.25]
    },

    "Contact Geometry": {
        "Shoe": {
            "Pad Dimensions": [0.11, 0.19, 0.06],
            "Pad Location": [0, 0, 0],
            "Guide Dimensions": [0.0284, 0.0114, 0.075],
            "Guide Location": [0.045, 0, 0.0375]
        },

        "Cylinder": {
            "Radius": 0.015,
            "Front Offset": 0.0535,
            "Rear Offset": -0.061
        }
    }
}
```
"Contact Material":
{
    "Coefficient of Friction": 0.8,
    "Coefficient of Restitution": 0.1,

    "Properties": {
        "Young Modulus": 1e7,
        "Poisson Ratio": 0.3
    },

    "Coefficients": {
        "Normal Stiffness": 2e5,
        "Normal Damping": 40.0,
        "Tangential Stiffness": 2e5,
        "Tangential Damping": 20.0
    }
},

"Visualization":
{
    "Mesh Filename": "M113/TrackShoe.obj",
    "Mesh Name": "TrackShoe_POV_geom"
}
}
Track-shoe Templates

Double-pin track-shoe
ChTrackShoeDoublePin geometry

- Double-pin, single-body track shoe
- Central guiding pin (i.e. consistent with ChDoubleIdler, ChDoubleRoadWheel)
- Connection to adjacent track shoe is through spherical joints (except the track loop closure)
- Revolute joints between shoe body and connector bodies
JSON specification for double-pin track-shoe (1/2)

```json
{
    "Name": "M113 DoublePin TrackShoe Left",
    "Type": "TrackShoe",
    "Template": "TrackShoeDoublePin",

    "Shoe": {
        "Length": 0.0984,
        "Width": 0.2781,
        "Height": 0.06,
        "Mass": 18.02,
        "Inertia": [0.22, 0.04, 0.25]
    },

    "Connector": {
        "Radius": 0.02,
        "Length": 0.054,
        "Width": 0.02,
        "Mass": 2.0,
        "Inertia": [0.1, 0.1, 0.1]
    },

    "Contact Geometry": {
        "Shoe": {
            "Pad Dimensions": [0.11, 0.19, 0.06],
            "Pad Location": [0, 0, 0],
            "Guide Dimensions": [0.0284, 0.0114, 0.075],
            "Guide Location": [0.045, 0, 0.0375]
        }
    }
}
```
"Contact Material":
{
    "Coefficient of Friction": 0.8,
    "Coefficient of Restitution": 0.1,

    "Properties": {
        "Young Modulus": 1e7,
        "Poisson Ratio": 0.3
    },

    "Coefficients": {
        "Normal Stiffness": 2e5,
        "Normal Damping": 40.0,
        "Tangential Stiffness": 2e5,
        "Tangential Damping": 20.0
    }
}
Idler Subsystem
ChIdler base class

• An idler subsystem consists of the idler wheel and a connecting body.
• The idler wheel is connected through a revolute joint to the connecting body which in turn is connected to the chassis through a translational joint.
• A linear actuator acts as a tensioner.

• An idler subsystem is defined with respect to a frame centered at the origin of the idler wheel, possibly pitched relative to the chassis reference frame.
• The translational joint is aligned with the x axis of this reference frame, while the axis of rotation of the revolute joint is aligned with its y axis.

```cpp
/// Base class for an idler subsystem.
/// An idler consists of the idler wheel and a connecting body. The idler wheel is connected
/// through a revolute joint to the connecting body which in turn is connected to the chassis
/// through a translational joint. A linear actuator acts as a tensioner.
class CH_VEHICLE_API ChIdler : public ChPart
```
ChIdler class members

• A ChIdler has:

```cpp
std::shared_ptr<ChBody> m_wheel;  ///< handle to the idler wheel body
std::shared_ptr<ChBody> m_carrier;  ///< handle to the carrier body
std::shared_ptr<ChLinkLockRevolute> m_revolute;  ///< handle to wheel-carrier revolute joint
std::shared_ptr<ChLinkLockPrismatic> m_prismatic;  ///< handle to carrier-chassis translational joint
std::shared_ptr<ChLinkSpringCB> m_tensioner;  ///< handle to the TSDA tensioner element

float m_friction;  ///< contact coefficient of friction
float m_restitution;  ///< contact coefficient of restitution
float m_young_modulus;  ///< contact material Young modulus
float m_poisson_ratio;  ///< contact material Poisson ratio
float m_kn;  ///< normal contact stiffness
float m_gn;  ///< normal contact damping
float m_kt;  ///< tangential contact stiffness
float m_gt;  ///< tangential contact damping
```
Idler Templates

Double idler
ChDoubleIdler geometry

gap

width

radius
JSON specification for double idler (1/2)

```json
{
    "Name": "M113 Double Idler Left",
    "Type": "Idler",
    "Template": "DoubleIdler",
    "Wheel": {
        "Radius": 0.255,
        "Width": 0.181,
        "Gap": 0.051,
        "Mass": 429.5,
        "COM": [0, 0, 0],
        "Inertia": [12.55, 14.70, 12.55]
    },
    "Carrier": {
        "Mass": 50.0,
        "COM": [0, -0.1, 0],
        "Inertia": [2, 2, 2],
        "Location Chassis": [0, -0.2, 0],
        "Visualization Radius": 0.02,
        "Pitch Angle": 0
    },
    "Tensioner": {
        "Location Carrier": [0, -0.2, 0],
        "Location Chassis": [0.5, -0.2, 0],
        "Preload": 2e4,
        "Free Length": 0.75,
        "Spring Coefficient": 1e6,
        "Damping Coefficient": 1.4e4
    }
}
```
"Contact Material":
{
    "Coefficient of Friction": 0.7,
    "Coefficient of Restitution": 0.1,
    "Properties": {
        "Young Modulus": 1e8,
        "Poisson Ratio": 0.3
    },
    "Coefficients": {
        "Normal Stiffness": 2e5,
        "Normal Damping": 40.0,
        "Tangential Stiffness": 2e5,
        "Tangential Damping": 20.0
    }
},

"Visualization":
{
    "Mesh Filename": "M113/Idler_L.obj",
    "Mesh Name": "Idler_L_POV_geom"
}
Brake Subsystem
ChTrackBrake base class

- Defines the common interface for any brake subsystem
- All classes defining particular brake templates inherit from ChTrackBrake

```cpp
///
/// Base class for a track brake subsystem
///
class CH_VEHICLE_API ChTrackBrake : public ChPart
```
Brake Templates
Simple track brake
ChTrackBrakeSimple

• Simple brake model using a constant torque opposing sprocket rotation.
• Uses a speed-dependent torque
• It cannot simulate sticking
• On initialization, it is associated with a revolute joint connecting the sprocket gear body
• Has a single parameter, the maximum braking torque
JSON specification file for TrackBrakeSimple

```json
{
  "Name": "M113 Simple Brake",
  "Type": "TrackBrake",
  "Template": "TrackBrakeSimple",
  "Maximum Torque": 10000
}
```
Driveline Subsystem
ChTrackDriveline base class

```cpp
/// Base class for a tracked vehicle driveline.
class CH_VEHICLE_API ChTrackDriveline : public ChPart
```
Driveline Templates

Simple driveline
JSON specification for simple track driveline

```json
{
    "Name": "M113 Simple Driveline",
    "Type": "TrackDriveline",
    "Template": "SimpleTrackDriveline",
    "Differential Max Bias": 1.0
}
```
Contact processing and monitoring
Sprocket – track shoe (single-pin)
Sprocket – track shoe (double-pin)
Contact monitoring

- A ChTrackVehicle embeds a contact monitoring object of type ChTrackContactManager
- Maintains lists of contacts on the two sprockets, two idler wheels, and one track shoe from each track assembly

```cpp
/// Class for monitoring contacts of tracked vehicle subsystems.
class ChTrackContactManager : public chrono::ChReportContactCallback {
  public:
    ChTrackContactManager();

    void MonitorContacts(int flags) { m_flags |= flags; }
    void SetContactCollection(bool val) { m_collect = val; }
    void WriteContacts(const std::string& filename);

    void SetTrackShoeIndexLeft(size_t idx) { m_shoe_index_L = idx; }
    void SetTrackShoeIndexRight(size_t idx) { m_shoe_index_R = idx; }

    void Process(ChTrackedVehicle* vehicle);
};
```
Enabling contact monitoring

• ChTrackedVehicle methods:

```cpp
/// Set contacts to be monitored.
/// Contact information will be tracked for the specified subsystems.
void MonitorContacts(int flags) { m_contacts->MonitorContacts(flags); }

/// Turn on/off contact data collection.
/// If enabled, contact information will be collected for all monitored subsystems.
void SetContactCollection(bool val) { m_contacts->SetContactCollection(val); }
```

• Example (flags can be OR-ed):

```cpp
vehicle.MonitorContacts(TrackCollide::SPROCKET_LEFT | TrackCollide::SHOES_LEFT | TrackCollide::IDLER_LEFT);
vehicle.SetContactCollection(true);
```

• Available flags:
SPROCKET_LEFT, SPROCKET_RIGHT, IDLER_LEFT, IDLER_RIGHT, SHOES_LEFT, SHOES_RIGHT
Monitoring contacts

- If enabled, contacts for the specified subsystems are rendered at run-time (Irrlicht): (slowed down 3x)
Monitoring contacts

- If data collection was enabled, contact information can be written to an output file

```cpp
/// Write contact information to file.
/// If data collection was enabled and at least one subsystem is monitored,
/// contact information is written (in CSV format) to the specified file.
void WriteContacts(const std::string& filename) { m_contacts->WriteContacts(filename); }
```

- Note: output not complete right now (WIP)
Sample simulations
M113 double-lane change (rigid terrain)
M113 double-lane change (rigid terrain)
M113 step climbing
M113 step climbing
M113 slide slope object avoidance (SCM terrain)
M113 slide slope object avoidance (SCM terrain)