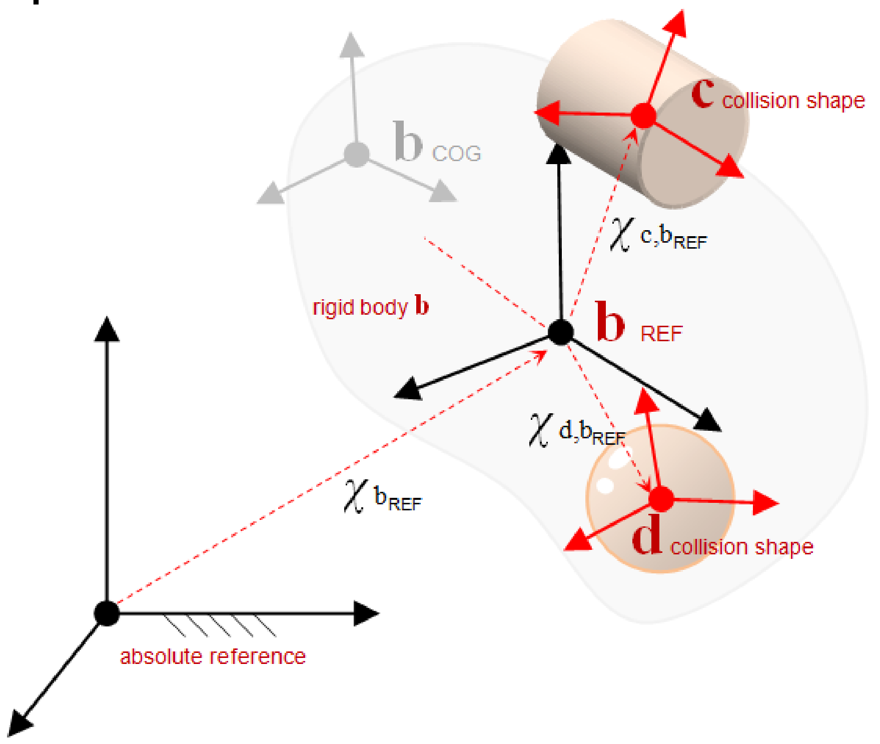
Collision detection in Chrono

Collision shapes

Collision shapes

- Collision shapes are defined respect to the REF frame of the body
- Spheres, boxes, cylinders, convex hulls, ellipsoids, compounds,…
- Concave shapes: decompose in compounds of convex shapes
- For simple ready-to-use bodies with predefined collision shapes, can use:
  - ChBodyEasySphere,
  - ChBodyEasyBox,
  - etc.



Specifying collision shapes

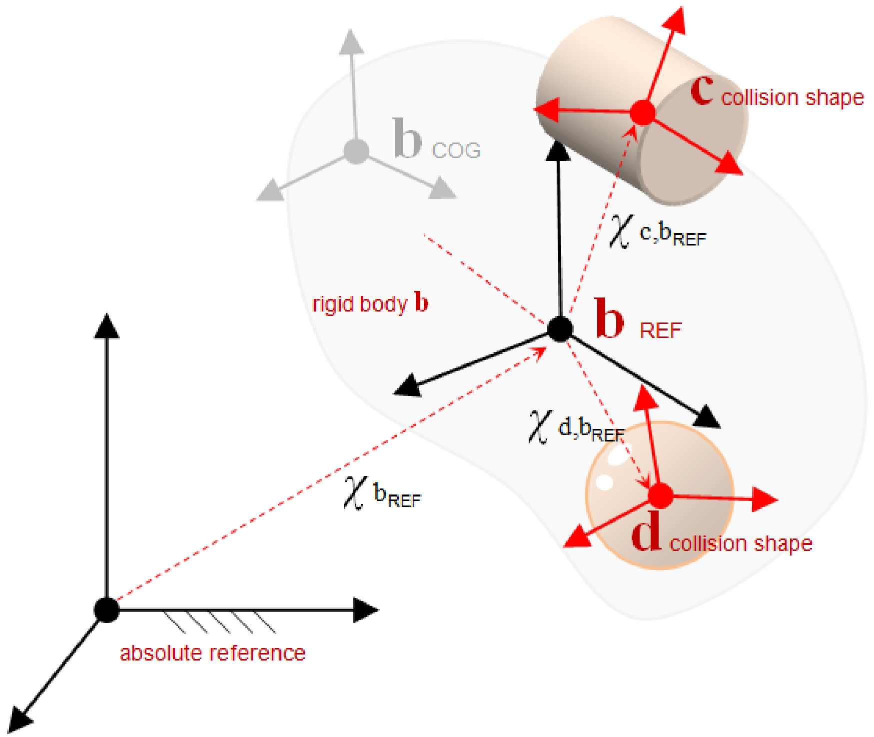
- Typical steps to setup collision:

```
body_b->GetCollisionModel()->ClearModel();
body_b->GetCollisionModel()->AddSphere(myradius);
...
body_b->GetCollisionModel()->BuildModel();
body_b->SetCollide(true);
```

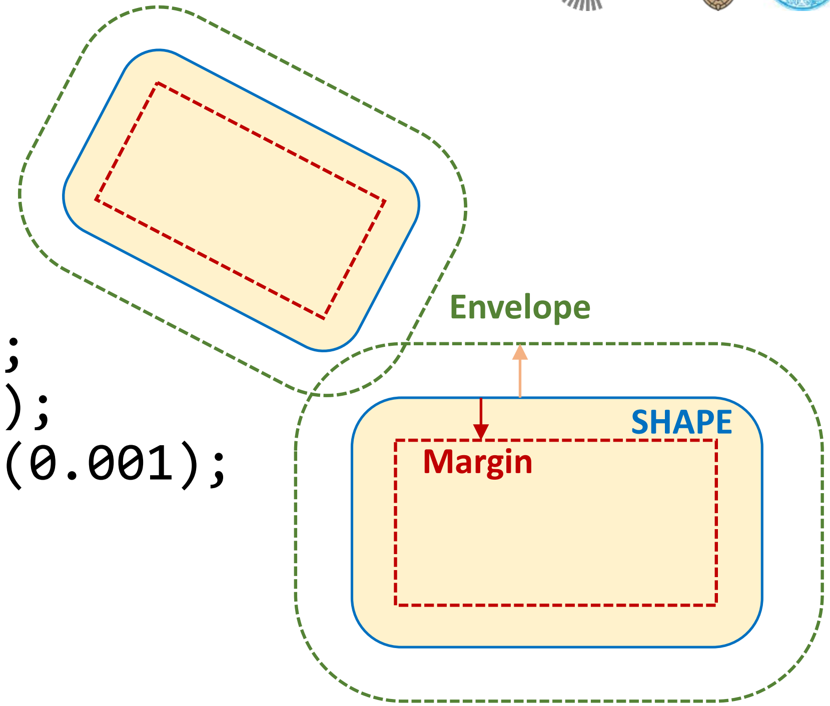
- Collision ‘families’ for selective collisions:

```
// Change from default collision family (0)
body_b->GetCollisionModel()->SetFamily(2);

body_b->SetFamilyMaskNoCollisionWithFamily(4);
```



Collision tolerances



- Set these tolerances before creating collision shapes:

```
ChCollisionModel::SetDefaultSuggestedEnvelope(0.001);
ChCollisionModel::SetDefaultSuggestedMargin  (0.0005);
ChCollisionSystemBullet::SetContactBreakingThreshold(0.001);
```

- Envelope (outward)
  - Represents the search volume for potential collision
  - Allows numerical schemes to anticipate collisions ahead of time
  - With zero envelope, the solver may first ‘see’ a collision with bodies already interpenetrated → inaccurate and shaky simulation
- Margin (inward)
  - Defines a range of penetrations within which faster collision detection algorithms can be safely used
- Contact breaking threshold
  - Distance beyond which contact between two shapes previously in contact is discarded
  - Bullet-specific setting (related to contact persistence in Bullet)

Recommendations

- Collision shapes and visualization assets do not need to match.
  - one may have a detailed visualization shape for rendering purposes, yet the collision shape is much simpler to avoid a slowdown of the simulation.
- Avoid shapes that are too thin, too flat, or in general that lead to extreme size ratios
- Use collision families to control what shapes interact through contact

- Collision tolerances:
  - ***Too large collision envelope***: too many potential contacts, high CPU time, high waste of RAM
  - ***Too small collision envelope***: risk of tunnelling effects, unstable simulation of stacked objects

  - ***Too large collision margin***: shapes are ‘rounded’ too much
  - ***Too small collision margin***: when interpenetration occurs beyond this value, an inefficient algorithm is used

Collision detection primer

Collision detection basics

- Collision detection implies:
  - Deciding what to test
  - Performing collision tests
    - Determining whether a collision occurred
    - Determining when a collision occurred
    - Determining where a collision occurred
  - Processing results
    - “Collision handling”

- A naïve approach is $O(n^2)$
  - Check for collisions between objects by comparing all possible combinations

Two-phase collision detection

1. Broad-phase
    - Find pairs to compare
    - Use bounding volumes (AABB, OBB, spheres)
    - Goals:
        - efficiently determine pairs of objects that cannot collide
        - accuracy is not a major concern

2. Narrow-phase
    - Compare individual pairs
    - Use exact shape geometry
    - Goals:
    - efficiently and accurately determine pairs of objects that do collide
    - completely characterize existing collisions (from a geometric point of view)

Broad-phase algorithms

- Dynamic AABB trees
  - well optimized, general-purpose broad-phase algorithm
  - structure adapts dynamically to the size of the scene and its contents
  - fast object addition/deletion
  - handles well scenes with many objects in motion

- Sweep and Prune (SAP)
  - good general-purpose broad-phase algorithm
  - best performance for dynamic world where most objects have little or no motion
  - limitation: requires scene of fixed size, known beforehand

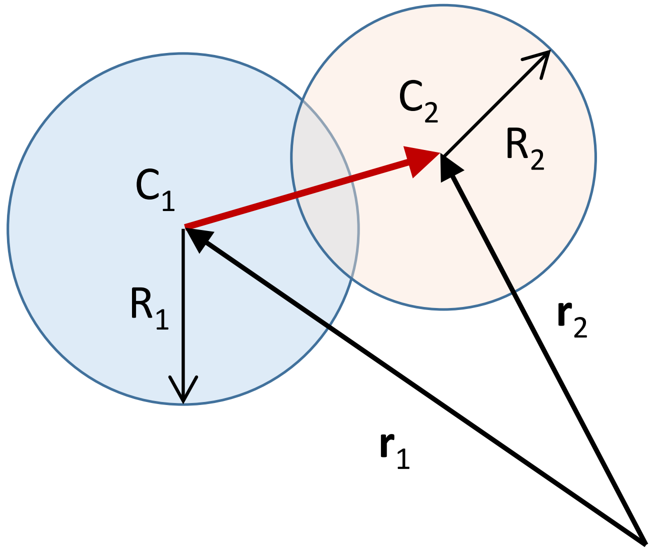
- Hierarchical grids
  - Good general-purpose broad-phase algorithm, based on binning
  - Relatively easy to parallelize
  - limitation: with few levels, performance decreases when object size varies very much

- Several other…

Narrow-phase algorithms

- Analytical methods for simple primitive shapes
  - Example: sphere-sphere collision

$$\delta = |C_1 C_2| - (R_1 + R_2)$$
$$\vec{n} = \overrightarrow{C_1 C_2} / |C_1 C_2|$$
$$\ldots$$

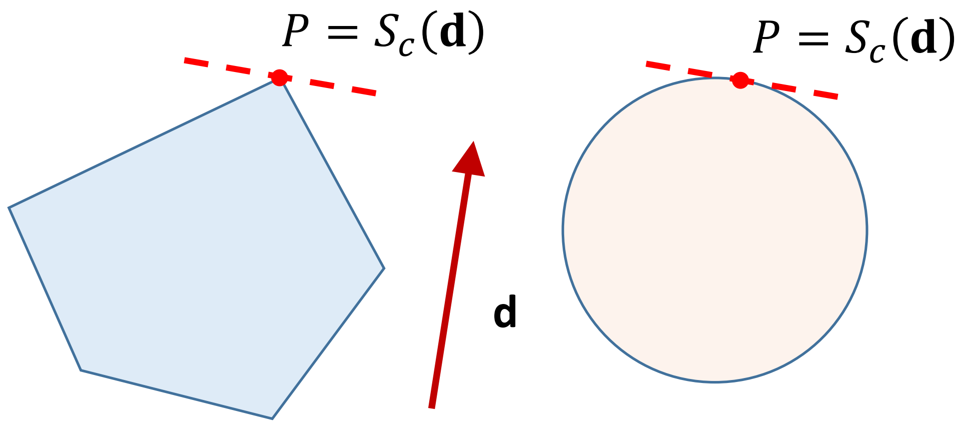


  - Can be defined for several primitive shape pairs (sphere-box, box-box, sphere-capsule, etc.)
  - Most efficient and accurate

- Separating Axis Theorem (SAT)
  - Test intersection of object projections on a set of different axes

Narrow-phase algorithms

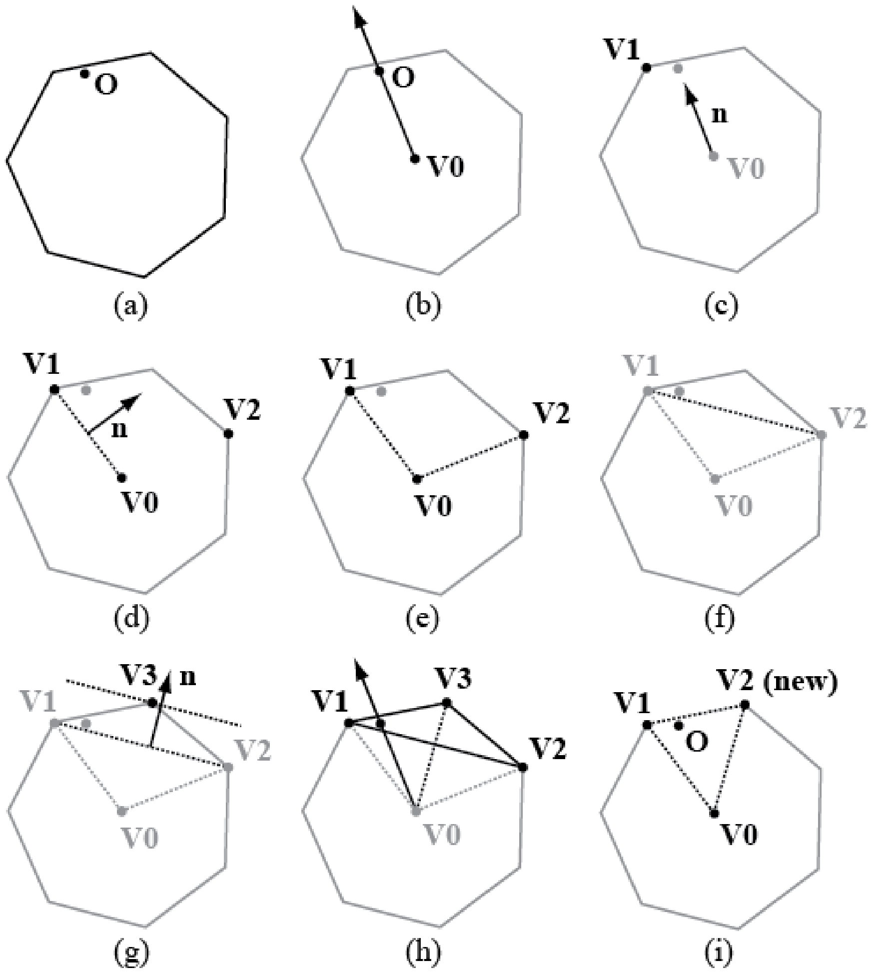
- Gilbert-Johnson-Keerthi (GJK) algorithm
  - Solves proximity queries for arbitrary convex objects (as long as they can be described in terms of a support mapping function)



  - Iterative process applied to the Minkovski difference of two polyhedra (A and B intersect ⇔ A-B contains the origin)

Narrow-phase algorithms

- Minkovski Portal Refinement (MPR)
  - Developed by Gary Snethen in 2006
  - Like GJK, relies on convex shapes that can be defined in terms of a support mapping function
  - Unlike GJK, does not provide the shortest distance between separated shapes
  - Simpler implementation and more numerically robust than GJK



http://xenocollide.snethen.com/

Collision detection algorithms in Chrono

- Chrono::Engine
  - Relies on Bullet (http://bulletphysics.org) for collision detection
  - Broad-phase: dynamic AABB trees
  - Narrow-phase: GJK

- Chrono::Parallel
  - Custom collision detection
  - Broad-phase: uniform binning (experimental 2-level grids)
  - Narrow-phase: hybrid (analytical/SAT – MPR)
  - Option for Bullet collision detection

Contact material properties

Specifying contact method at system construction (1/3)

- The contact method is implicitly specified by the type of physical system constructed
- The class ChSystemNSC uses the complementarity approach to treat contacts (if any)

```
class ChApi ChSystemNSC : public ChSystem {
    /// Create a physical system.
    /// Note, in case you will use collision detection, the values of
    /// 'max_objects' and 'scene_size' can be used to initialize the broadphase
    /// collision algorithm in an optimal way. Scene size should be approximately
    /// the radius of the expected area where colliding objects will move.
    /// Note that currently, by default, the collision broadphase is a btDbvtBroadphase
    /// that does not make use of max_objects and scene_size, but one might plug-in
    /// other collision engines that might use those parameters.
    /// If init_sys is false it does not initialize the collision system or solver
    /// assumes that the user will do so.
    ChSystemNSC(unsigned int max_objects = 16000, double scene_size = 500, bool init_sys = true);
```

- The class ChSystemSMC employs the penalty approach to treat contacts

```
class ChApi ChSystemSMC : public ChSystem {
    /// Constructor for ChSystemDEM.
    /// Note that, in case you will use collision detection, the values of
    /// 'max_objects' and 'scene_size' can be used to initialize the broadphase
    /// collision algorithm in an optimal way. Scene size should be approximately
    /// the radius of the expected area where colliding objects will move.
    ChSystemSMC(bool use_material_properties = true,  ///< use physical contact material properties
                unsigned int max_objects = 16000,     ///< maximum number of contactable objects
                double scene_size = 500               ///< approximate bounding radius of the scene
                );
```

Specifying contact method at system construction (2/3)

- Bodies must be constructed to be consistent with the containing system:

```
ChBody(ChMaterialSurface::ContactMethod contact_method = ChMaterialSurface::NSC);

// Defined in ChMaterialSurfaceBase.h
enum ContactMethod {
     NSC,  ///< constraint-based (a.k.a. rigid-body) contact
     SMC   ///< penalty-based (a.k.a. soft-body) contact
};
```

- ChBody getter and setter methods for contact material:

```
    /// Access the NSC material surface properties associated with this body.
    /// This function performs a dynamic cast (and returns an empty pointer
    /// if matsurface is in fact of SMC type).  As such, it must return a copy
    /// of the shared pointer and is therefore NOT thread safe.
    std::shared_ptr<ChMaterialSurfaceNSC> GetMaterialSurfaceNSC() {
        return std::dynamic_pointer_cast<ChMaterialSurfaceNSC>(matsurface);
    }

    /// Access the SMC material surface properties associated with this body.
    /// This function performs a dynamic cast (and returns an empty pointer
    /// if matsurface is in fact of NSC type).  As such, it must return a copy
    /// of the shared pointer and is therefore NOT thread safe.
    std::shared_ptr<ChMaterialSurfaceSMC> GetMaterialSurfaceSMC() {
        return std::dynamic_pointer_cast<ChMaterialSurfaceSMC>(matsurface);
    }

    /// Set the material surface properties by passing a ChMaterialSurfaceNSC or
    /// ChMaterialSurfaceSMC object.
    void SetMaterialSurface(const std::shared_ptr<ChMaterialSurface>& mnewsurf) { matsurface = mnewsurf; }
```

Specifying contact method at system construction (3/3)

- ChSystem virtual method for constructing a body with consistent contact material:
  - ChSystemNSC

```
/// Create and return the pointer to a new body.
/// The returned body is created with a contact model consistent with the type
/// of this Chsystem and with the collision system currently associated with this
/// ChSystem.  Note that the body is *not* attached to this system.
virtual ChBody* NewBody() { return new ChBody(ChMaterialSurface::NSC); }
```

  - ChSystemDEM

```
/// Create and return the pointer to a new body.
/// The returned body is created with a contact model consistent with the type
/// of this Chsystem and with the collision system currently associated with this
/// ChSystem.  Note that the body is *not* attached to this system.
virtual ChBody* NewBody() { return new ChBody(ChMaterialSurface::SMC); }
```

- Example: construct a system with specified contact method and create a body with consistent contact material

```
ChSystem* system;

switch (contact_method) {
    case ChMaterialSurface::NSC:
        system = new ChSystemNSC();
        break;
    case ChMaterialSurface::SMC:
        system = new ChSystemSMC(use_mat_properties);
        break;
}

auto object = std::shared_ptr<ChBody>(system->NewBody());
system->AddBody(object);
```

ChMaterialSurfaceNSC and ChMaterialSurfaceSMC

Complementarity

```
/// Material surface data for NSC contact
class ChApi ChMaterialSurfaceNSC : public ChMaterialSurface
{
  public:
    float static_friction;
    float sliding_friction;
    float rolling_friction;
    float spinning_friction;
    float restitution;
    float cohesion;
    float dampingf;
    float compliance;
    float complianceT;
    float complianceRoll;
    float complianceSpin;
```

Penalty

```
/// Material surface data for SMC contact
class ChApi ChMaterialSurfaceSMC : public ChMaterialSurface
{
  public:
    float young_modulus;      ///< Young's modulus (elastic modulus)
    float poisson_ratio;      ///< Poisson ratio
    float static_friction;    ///< Static coefficient of friction
    float sliding_friction;   ///< Kinetic coefficient of friction
    float restitution;        ///< Coefficient of restitution
    float constant_adhesion;  ///< Constant adhesion force
    float adhesionMultDMT;    ///< Adhesion multiplier used in DMT model.

    float kn;  ///< user-specified normal stiffness coefficient
    float kt;  ///< user-specified tangential stiffness coefficient
    float gn;  ///< user-specified normal damping coefficient
    float gt;  ///< user-specified tangential damping coefficient
```

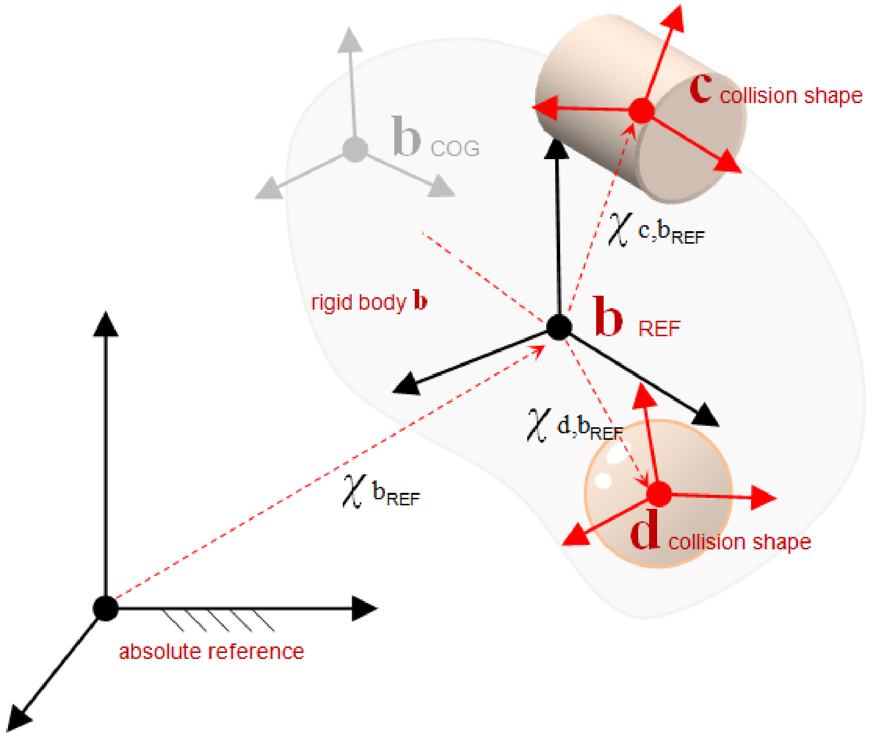
Specifying collision material (1/2)

- Easy but potentially memory-inefficient:

```
body_b->SetFriction(0.4f);
body_b->SetRollingFriction(0.001f);
```

- Using a shared material:

```
// Create a surface material and change properties:
auto mat = std::make_shared<ChMaterialSurfaceNSC>();
mat->SetFriction(0.4f);
mat->SetRollingFriction(0.001f);
// Assign surface material to body/bodies:
body_b->SetSurfaceMaterial(mat);
body_c->SetSurfaceMaterial(mat);
body_d->SetSurfaceMaterial(mat);
. . .
```



- Note: ChMaterialSurfaceSMC can only be set through a shared pointer

Specifying collision material (2/2)

```
auto object = std::shared_ptr<ChBody>(system->NewBody());
system->AddBody(object);

object->SetIdentifier(objectId);
object->SetMass(mass);
object->SetInertiaXX(400.0 * ChVector<>(1, 1, 1));
object->SetPos(pos);
object->SetRot(rot);
object->SetPos_dt(init_vel);
object->SetWvel_par(init_omg);
object->SetCollide(true);
object->SetBodyFixed(false);

switch (object->GetContactMethod()) {
    case ChMaterialSurface::NSC:
        object->GetMaterialSurfaceNSC()->SetFriction(object_friction);
        object->GetMaterialSurfaceNSC()->SetRestitution(object_restitution);
        break;
    case ChMaterialSurface::SMC:
        object->GetMaterialSurfaceSMC()->SetFriction(object_friction);
        object->GetMaterialSurfaceSMC()->SetRestitution(object_restitution);
        object->GetMaterialSurfaceSMC()->SetYoungModulus(object_young_modulus);
        object->GetMaterialSurfaceSMC()->SetPoissonRatio(object_poisson_ratio);
        object->GetMaterialSurfaceSMC()->SetKn(object_kn);
        object->GetMaterialSurfaceSMC()->SetGn(object_gn);
        object->GetMaterialSurfaceSMC()->SetKt(object_kt);
        object->GetMaterialSurfaceSMC()->SetGt(object_gt);
        break;
}
```