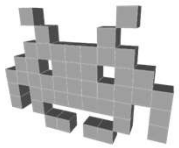
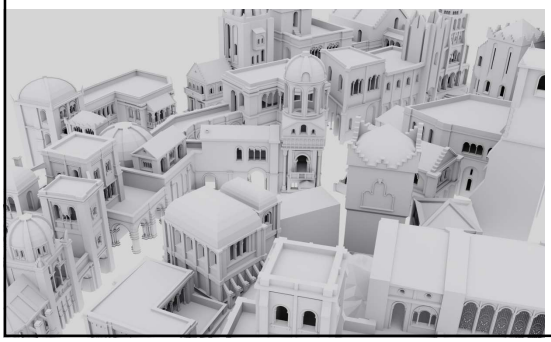
3D video games 2020/2021

the Scene Graph



Marco Tarini



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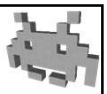
Course Plan



lec. 1: **Introduction**
lec. 2: **Mathematics** for 3D Games
lec. 3: **Scene Graph**
lec. 4: Game **3D Physics** +
lec. 5: Game **Particle Systems**
lec. 6: Game **3D Models**
lec. 7: Game **Textures**
lec. 8: Game **3D Animations**
lec. 9: Game **3D Audio**
lec. 10: **Networking** for 3D Games
lec. 11: **Artificial Intelligence** for 3D Games
lec. 12: Game **3D Rendering Techniques**

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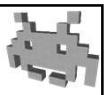
Recap: 3D Spatial Trasforms



- Math functions
  - input: point / vector / versor
  - output: point / vector / versor

Thus, can be applied to any 3D thing (apply them to all positions directions etc …)

- Three components:
  - Scaling
  - Rotation
  - Translation

… modelling the State / Act of:

- Size / Scale up (if > 1), down (if <1)
- Orientation / Rotate
- Position / Displace

can be "uniform" ("isotropic")
or not ("anisotropic", different factors in X,Y,Z)

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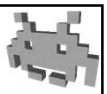
Recap: transformation associated to an object in the scene



- Any object associated to a spatial location in the game is given its transformation, which goes
- From:
  - local space *a.k.a.*
  - object space *a.k.a.*
  - pre-transform space
  - *a.k.a.* «*castle*» space / «*hero*» space / «*camera*» space / «*chainsaw*» space / «*bazooka*» space / etc
- To:
  - global space *a.k.a.*
  - world space *a.k.a.*
  - post-transform space

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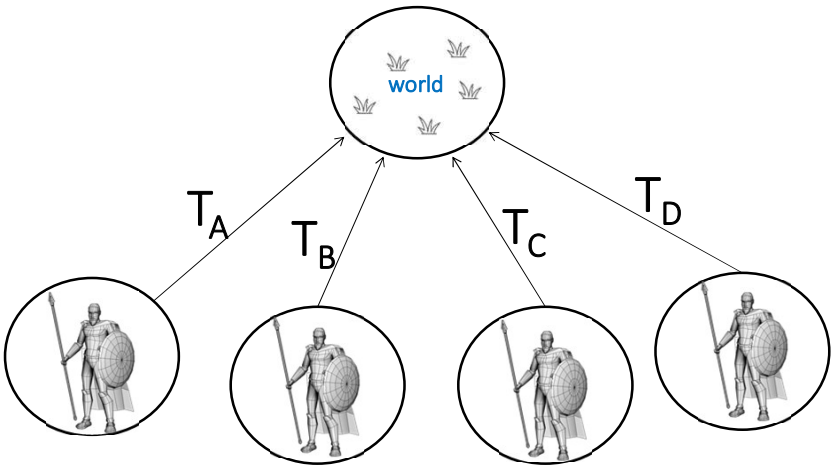
Transforms associated to each object in game



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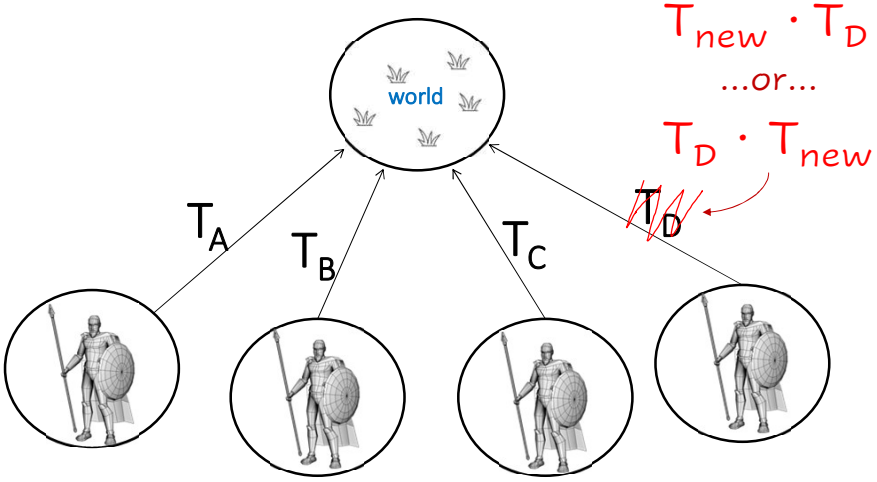
Moving objects around = updating their transforms



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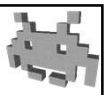
Moving objects: two ways of updating per-object Transforms



- Let T_{new} be a new transformation to be applied to move object D (w.r.t. its current placement)
  - Say: **rotation** = ide **scaling** = 1 **translation** = (-2,0,0)
  - T_{new} = "*move two units to the left*" (assuming X = right)
- How to update transformation T_D ? Two ways:
  - $T_D \leftarrow T_D \cdot T_{new}$ = object D moves 2 units on its left
  - $T_D \leftarrow T_{new} \cdot T_D$ = object D moves 2 units on world's left (meaning, i.e., "*West-ward*")

We call this "applying the new transformation in local space" or "in global space respectively"
E.g., in unity: see parameter "relativeTo" of method Transform.Translate

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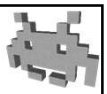
Moving objects: two ways of updating per-object Transforms



- Let T_{new} be a new transformation to be applied to change object D (w.r.t. its current placement)
  - Say: **rotation** = ide **scaling** = 2 **translation** = (0,0,0)
  - T_{new} = "*double by ×2*" (note: volume gets ×8 bigger)
- How to update transformation T_D ? Two ways:
  - $T_D \leftarrow T_D \cdot T_{new}$ = object D enlarges from its center
  - $T_D \leftarrow T_{new} \cdot T_D$ = object D enlarges from world's center (i.e. moves away from it too)

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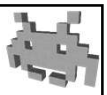
Moving object: two ways of updating per-object Transforms



- Let T_{new} be a new transformation to be applied to change object D (w.r.t. its current placement)
  - Say: **rotation** = *j* **scaling** = 1 **translation** = (0,0,0)
  - T_{new} = "*flip by* 180° *around Up axis*" (assuming Y = up)
- How to update transformation T_D ? Two ways:
  - $T_D \leftarrow T_D \cdot T_{new}$ = object D rotates around its up axis (e.g. goes supine to prone if was laying down)
  - $T_D \leftarrow T_{new} \cdot T_D$ = object D rotates in world's up axis

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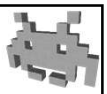
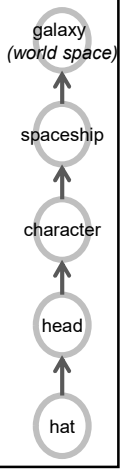
Composite scenes: hierarchical transformations



- So far, we assumed that the transform of each object goes from local to global in one step
- In reality, scenes can be defined hierarchically
- That is, objects have sub-objects in them
  - a «city» is made of «houses» made of «walls» made of «bricks»
  - a «hat» sits on an «head» which is part of a «character» who sits in a «spaceship» moving across the «galaxy»
  - a car is a «hull» plus four «wheels»



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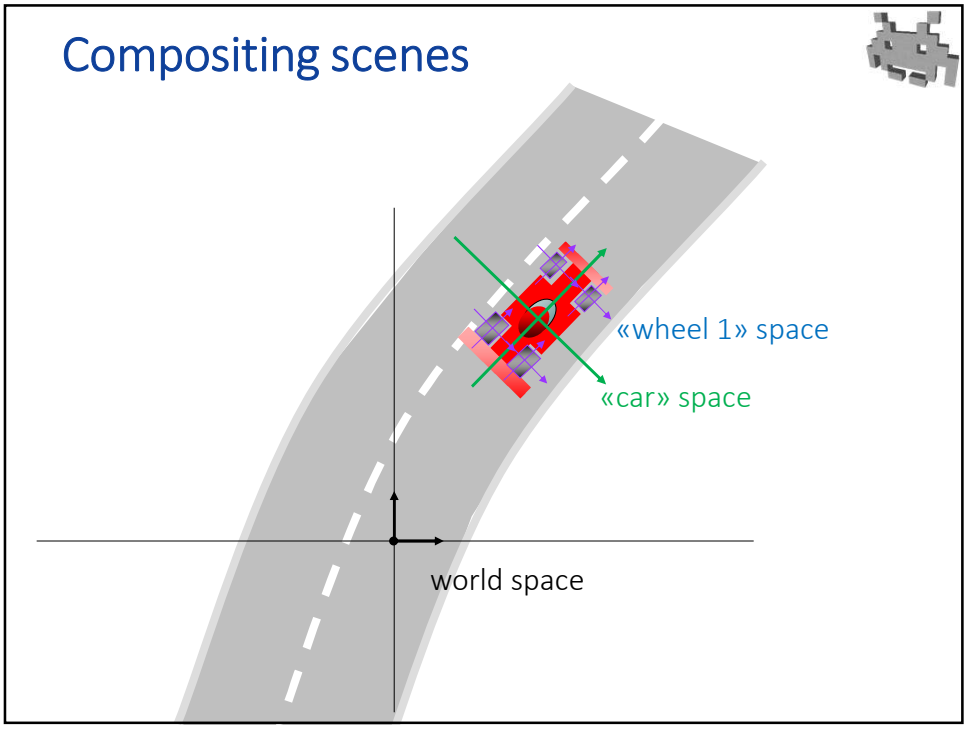
Compositing scenes



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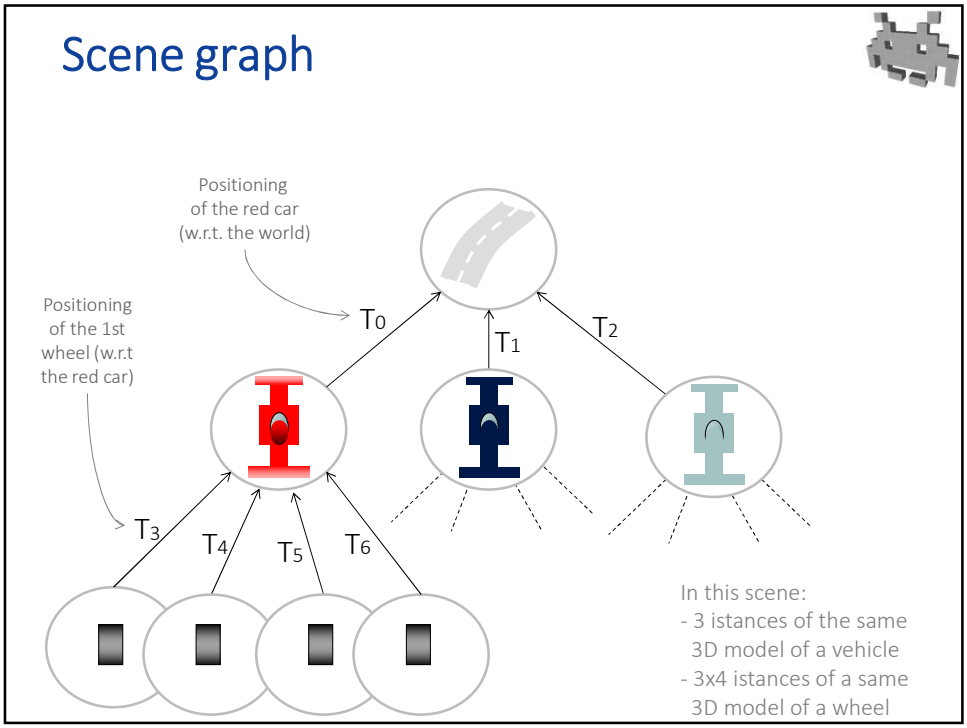
Scene graph



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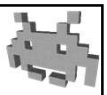
Composite scenes: multi-instancing



- Each node contains a reference / pointer / index to one 3D object (e.g. a 3D mesh, etc)model
  - E.g. all wheels of all cars are the same “wheel” model
- Different *instances* of the same object can appear in multiple locations of the scene
  - E.g. all wheels of all cars are the same “wheel” model
  - Advantage:
    only one 3D model in RAM,
    but many identical 3D models on the screen
  - Each model is associated to a different transform, plus other data, e.g. different “materials”

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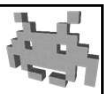
Scene graph



A tree (i.e. a hierarchical structure)

- Each nodes has its own space (a reference frame)
  - The Local Space of that node
- To each node we associate:
  - Instances to… stuff:
    anything at all that has a place in the virtual scene:
  - 3D models, lights, cameras, virtual microphones
    spawn points, explosions, etc
- Root node: world space
  - Global Space = local space of the root
- To each arch: we associate the “local” transform
  - the transform going from the local space of that arch to the local space of its parent

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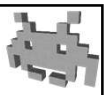
Local VS Global Transform[-ation]s



- Local transform (a.k.a. «relative» transform)
  - from the local space of a node to the local space of its parent space
  - Stored per object!
- Global transform (a.k.a. «absolute» transform)
  - from the local space of a node to the world space (which the "local" space of the root)
  - Procedurally obtained/defined by: *cumulating* local transforms to the root
- benefit: changing the transform associated to a node affects its entire subtree

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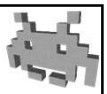
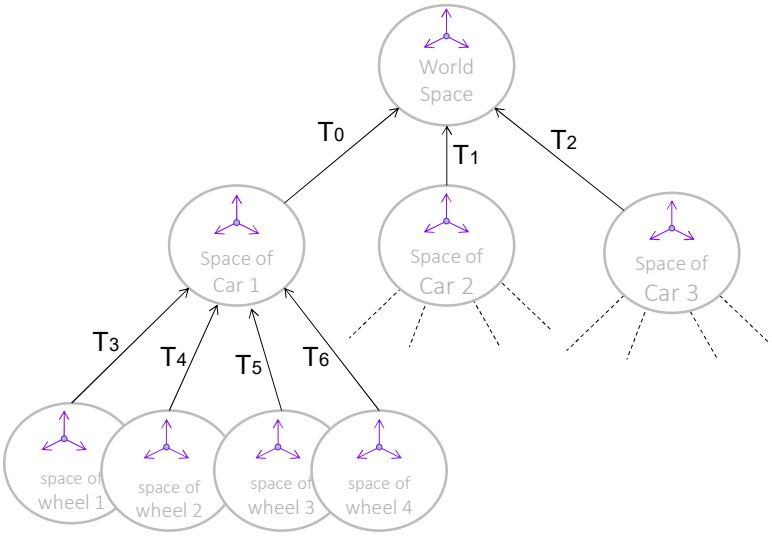
Scene graph





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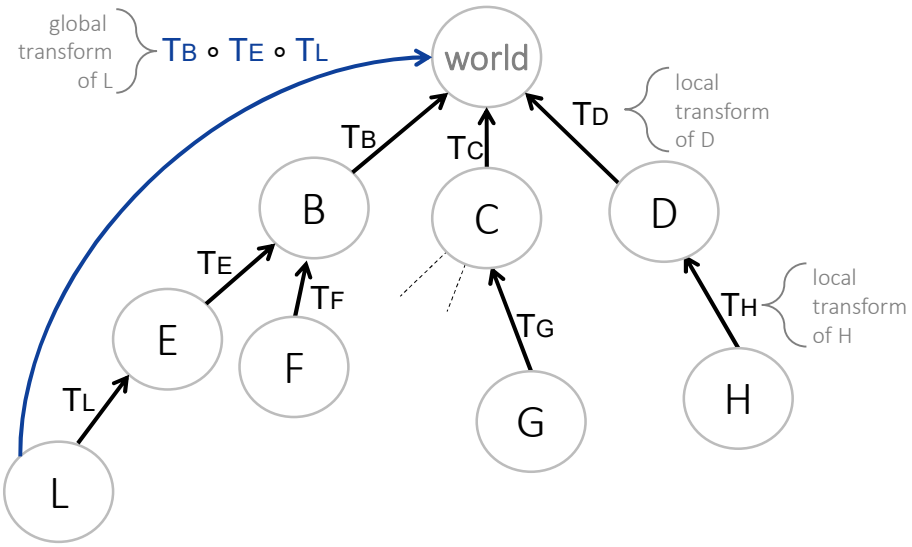
Local VS Global Transforms



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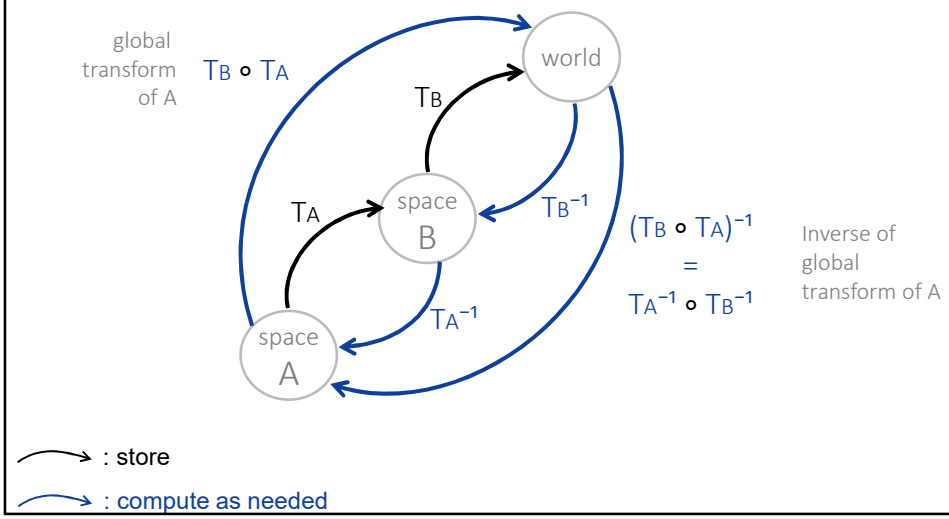
Reminder: inverse of a composite transform (or, in general, function)



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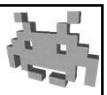
Reminder: inverse of a composite transform (or, in general, function)



$$(T_B \circ T_A)^{-1} = T_A^{-1} \circ T_B^{-1}$$

- The inverse of "first Ta then Tb" is "the inverse of Tb" followed by "the inverse of Ta"
- As it's natural! If you…
  - "take a step *forward*, *then,* turn by 90° *clockwise*"

  …then, to go back to the starting pos, you need to…
  - "turn by 90° *counter-clockwise*, *then*, take a step *backward*"

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