An Open Simulation Framework for Immersive and Non-Immersive Accessibility Engineering

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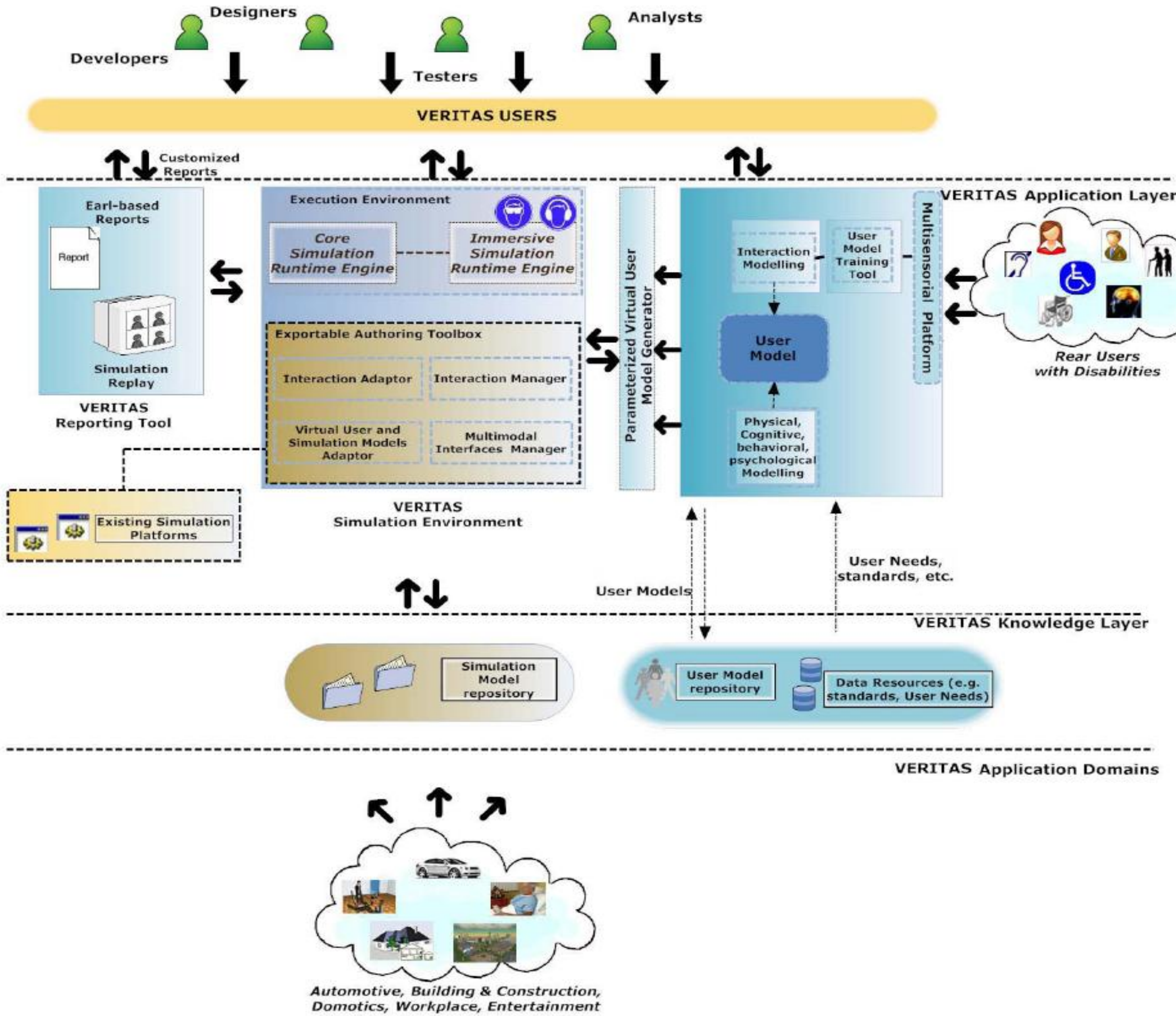
Introduction:
the problem

- "Design for All": There will always be a minority of disabled people with severe impairments who need adaptations or specialized products.
- Goods and services can and should be designed to meet the needs of a wide range of people, including people with disabilities. *Product designs can be changed, but people's abilities or age cannot.*
- Most of the current accessibility assessment tools are restricted to:
  - support of only fully-capable user models leaving out the elderly and impaired populations (examples: RAMSIS, ANNIE-Ergoman, JACK).
  - taking into account a small list of impairment simulation, i.e. only vision, only hearing, leaving out biomechanical simulations (example: ACCESSIBLE).
  - kinematic only based simulators, ignoring the human's dynamic properties, i.e. forces and torques (example: SAMMIE-CAD).

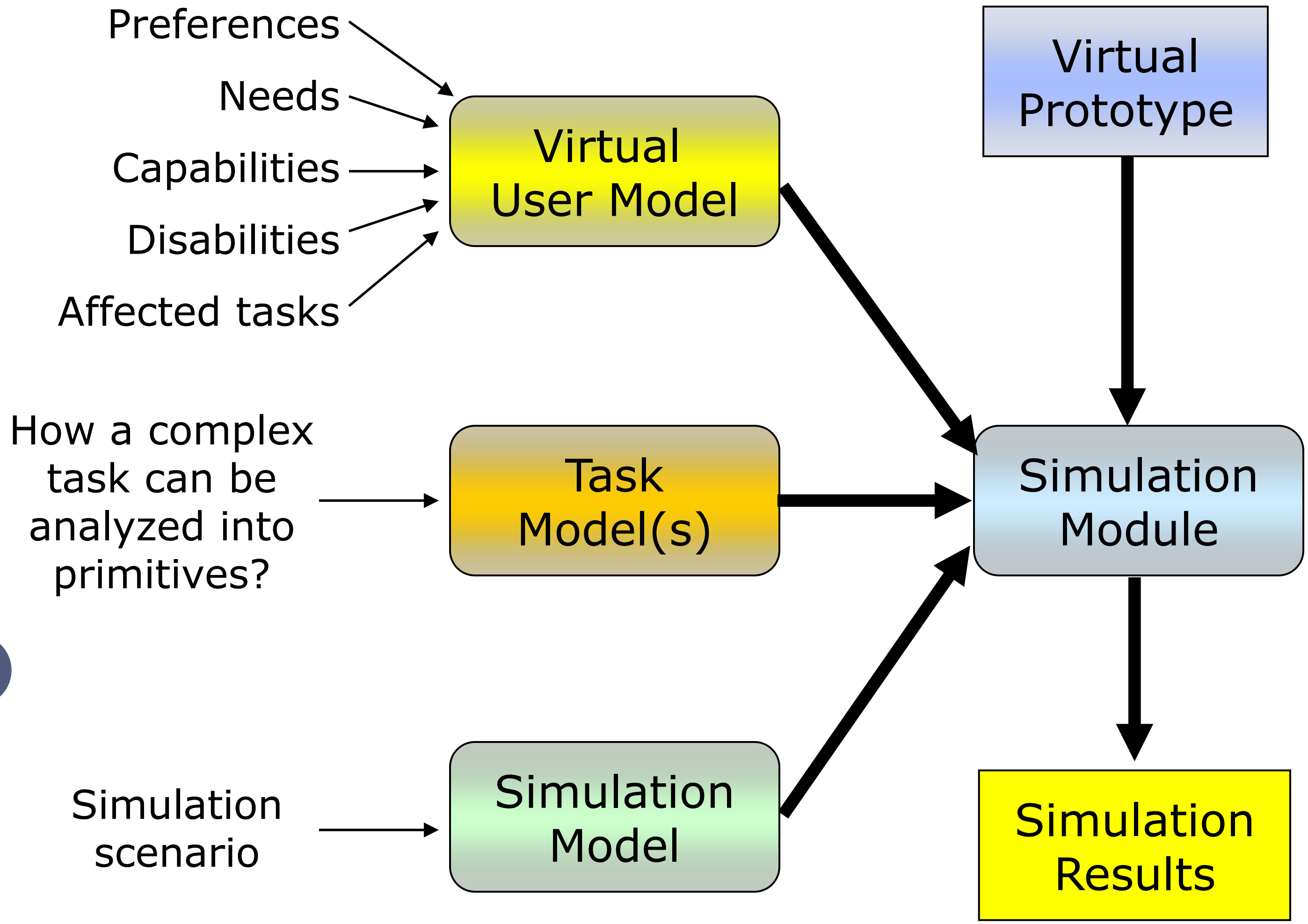
Introduction:
the motivation

- Enabling the automatic accessibility evaluation of any environment for any user category by testing its equivalent virtual environment for the corresponding virtual user provides:
  - very fast immediate accessibility assessment results,
  - low development costs,
  - product can address to even larger parts of the population.
- It becomes clear that there is a need of a holistic framework that supports comprehensive virtual user modeling, simulation and testing at all development stages.
- This lack will be filled by a framework that is
  - capable of simulating virtual users of several capability levels (fully capable, impaired, erderly)
  - in several modality fields, such as: motor, vision, hearing, speech, cognition / behaviour, and
  - provide valid accessibility assessment to the end user.

System Architecture

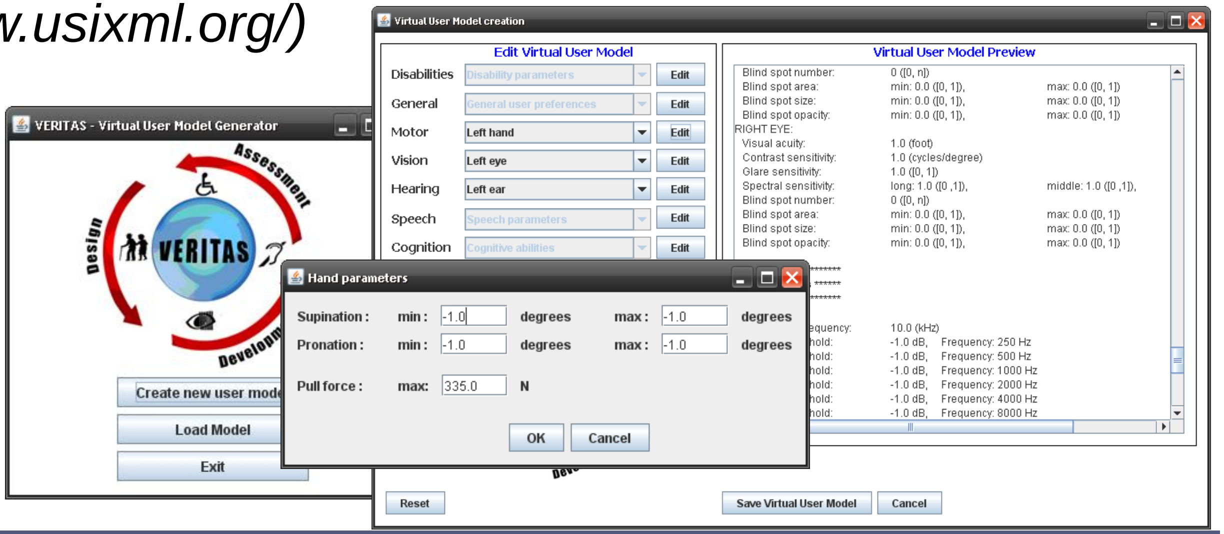


Framework Input



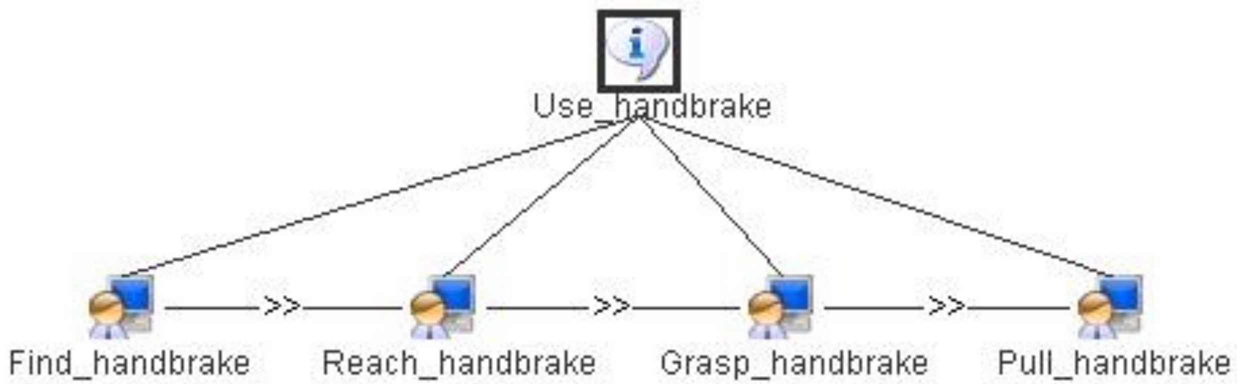
Framework Input: Virtual User Model

- An instance of a virtual user, including user's
  - Needs, e.g. unsuitable input/output modality
  - Preferences, e.g. preferred input/output modality
  - All the possible disabilities of the user
  - The affected (by the disabilities) tasks
  - Motor, visual, hearing, speech, cognitive and behavioral user characteristics
- It is modelled through an extension of UsiXML *(http://www.usixml.org/)*



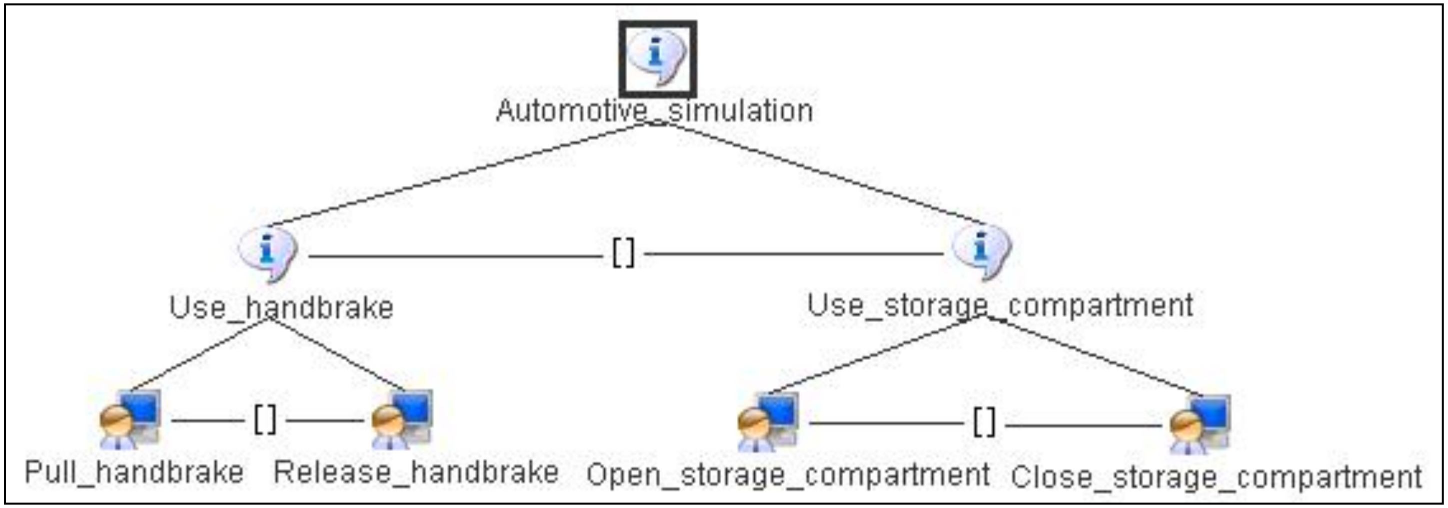
Framework Input:
Task Model

- Task models describe the interaction between the virtual user and the virtual environment.
- User tasks are divided into
  - primitive
    - e.g. grasp, pull, walk, etc.
  - complex
    - e.g. driving, telephone use, computer use, etc.
- For each complex task a Task Model is developed, in order to specify how the complex task can be analyzed into primitive tasks.
- It is expressed in UsiXML



Framework Input: Simulation Model

- A Simulation Model refers to a specific product or service and describes all the functionalities of the product/service as well as the involved interaction with the user, including all the different interaction modalities supported.
- Simulation Model = Simulation Scenario
- It is expressed in UsiXML

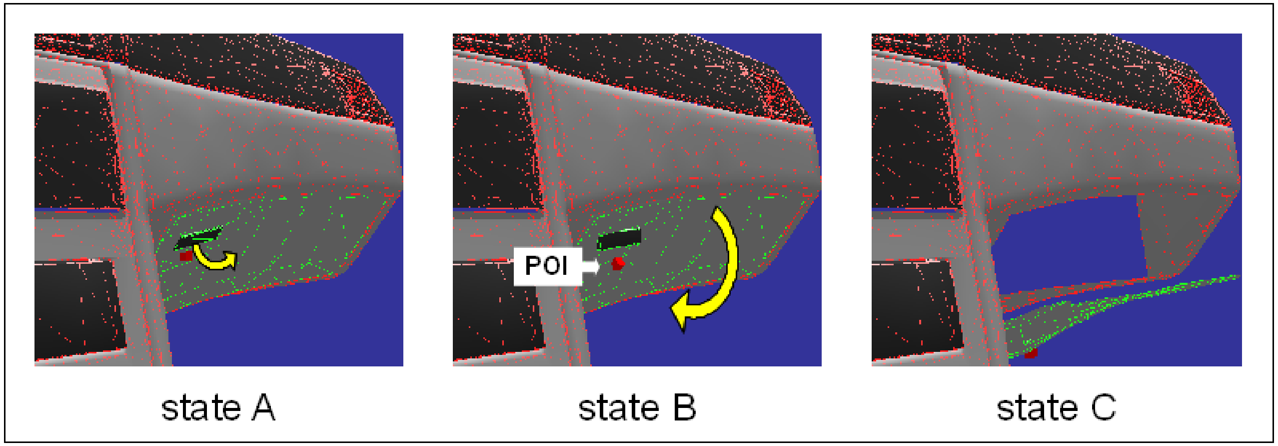


Simulation Framework Analysis

- The simulation framework supports two modes:
  - **Immersive**, where the end user’s is provided with an altered and filtered audio-visual enviroment.
  - **Non Immersive**, where all the biomechanical functions of an virtual user (avatar) are simulated by the system.
- The simulation framework consists of four basic modules:
  - **Simulation module:** simulates the whole process by managing the following three entities.
  - **Scene module:** responsible for creating the scene, managing the objects in it and defining their special attributes.
  - **Humanoid module:** responsible for manipulating the simulated virtual user capabilities.
  - **Task manager module:** responsible for managing the actions of the humanoid in order to provide a solution to a given task.

Virtual Environment Simulation: Scene Module

- Creates/imports the scene, manages the objects in it and defines their special attributes.
- Supports static and moveable objects, having a parameterisable number of degrees of freedom (DoF). Complex object geometries are supported
- Each object functionality can be simulated by a set of rules, containing conditions and resulted actions.

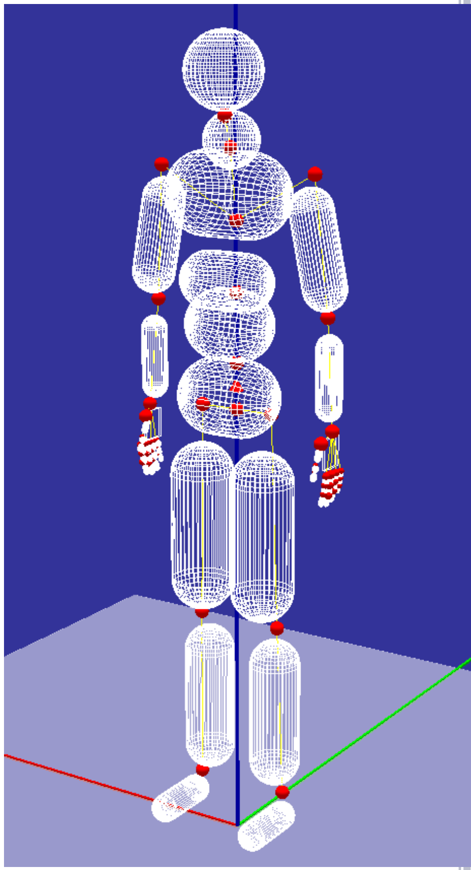


Avatar Simulation: Humanoid Module

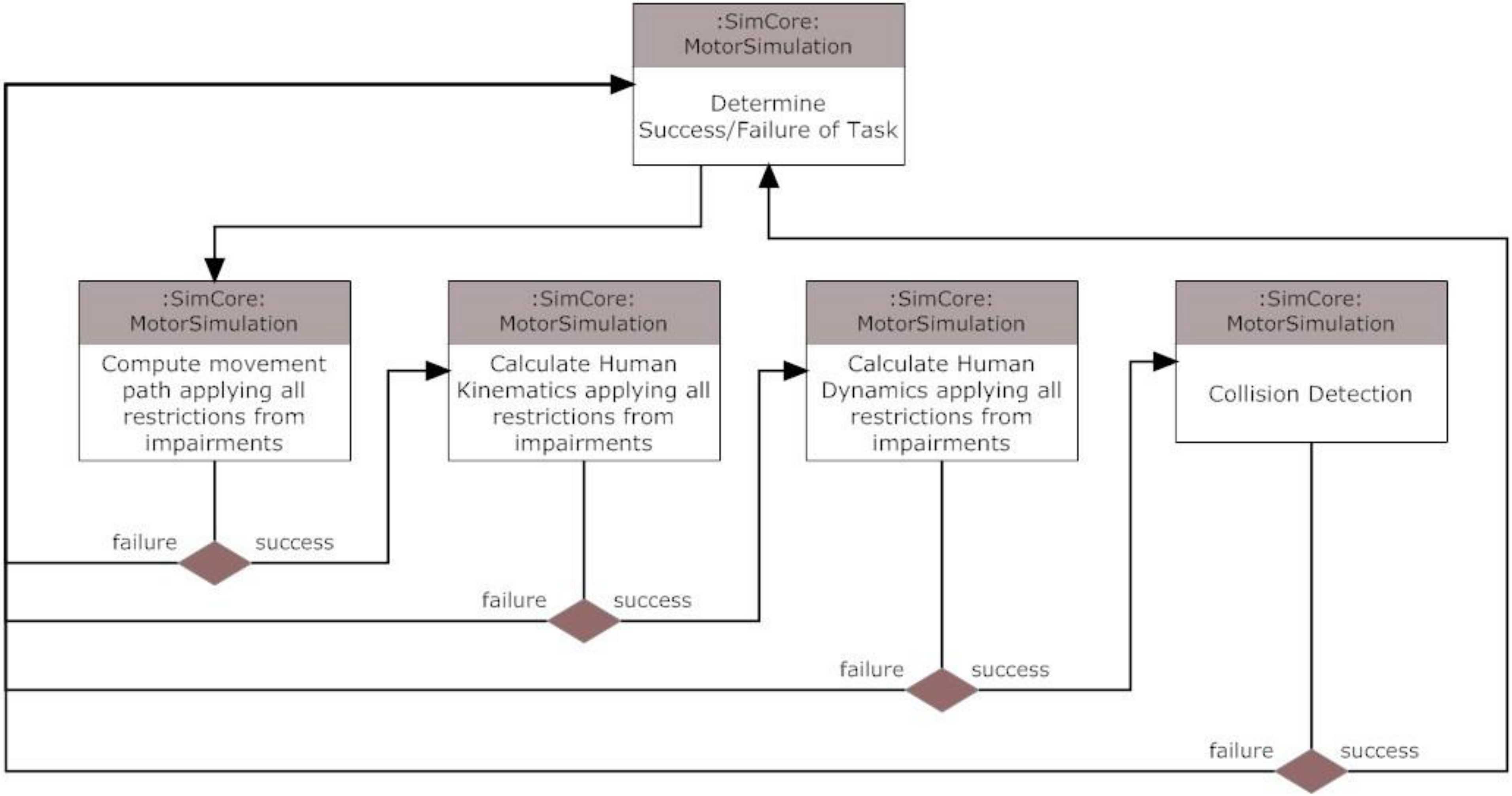
- The humanoid module is responsible for simulating the avatar's capabilities.
- The humanoid capabilities are distinguished by their modality in four different simulation domains:
  - Motor simulation: simulates avatar movements.
  - Vision simulation: computes the filtered image of the world as it is projected to the avatar's eyes.
  - Auditory simulation: responsible for the transformed audio signals that the avatar is able to hear. Also used for speech purposes.
  - Cognition simulation: simulates the avatar's context awareness interpretation.

Motor capabilities simulation

- Avatar
  - skeletal structure
  - rigid bones connected by joints with properties such as
    - range of motion,
    - maximum strength, velocity
    - comfort factors,
- Pure kinematic motor simulation by using forward and inverse kinematics algorithms. IK take into consideration avatar's comfort
- Fully dynamic motor simulation by using forward and inverse dynamics. Avatar is set on motion by generating torques at its joints
- Whole body collision avoidance based on rapid motion planning
- Automated object grasping, humanoid locomotion and gait generation is also supported.

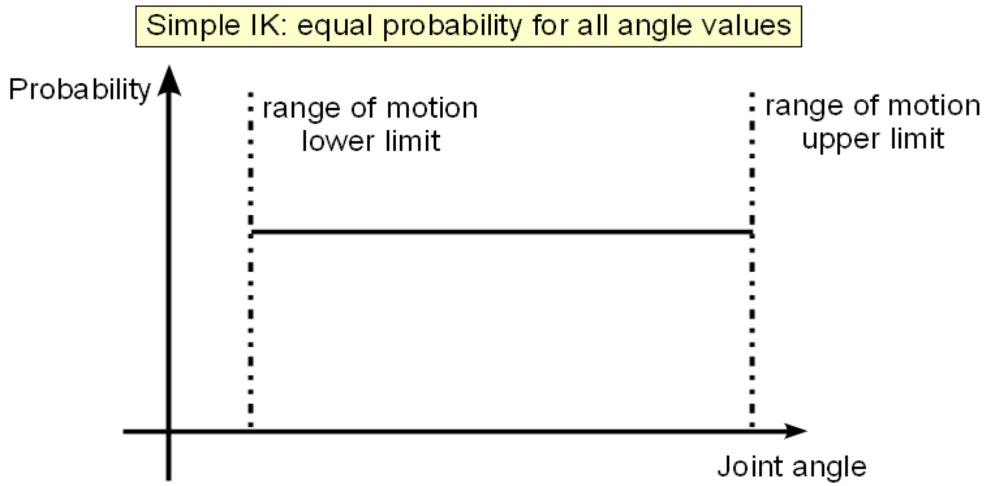


Motor capabilities simulation



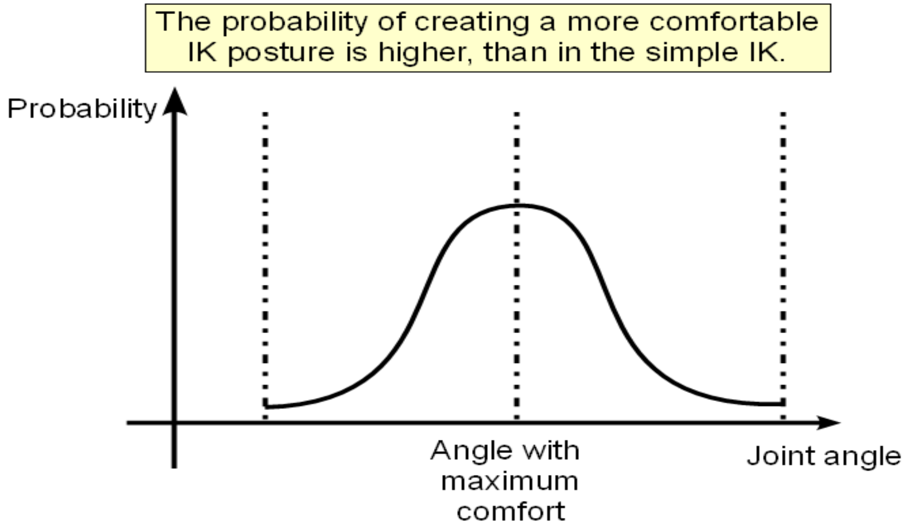
Simple Inverse Kinematics: the problem

- Multiple solutions can be produced when the end effector's number of DoF is smaller than the DoF number the IK chain's joints.
- Simple inverse kinematics algorithms do not compensate properly with this fact and produce most of the times postures that are not considered comfortable and realistic.
- In the above case, the probability of selecting a specific angle (inside the IK joint range of motion) when computing the IK solution, follows a uniform distribution: all available DoF angles can be selected with equal probability.

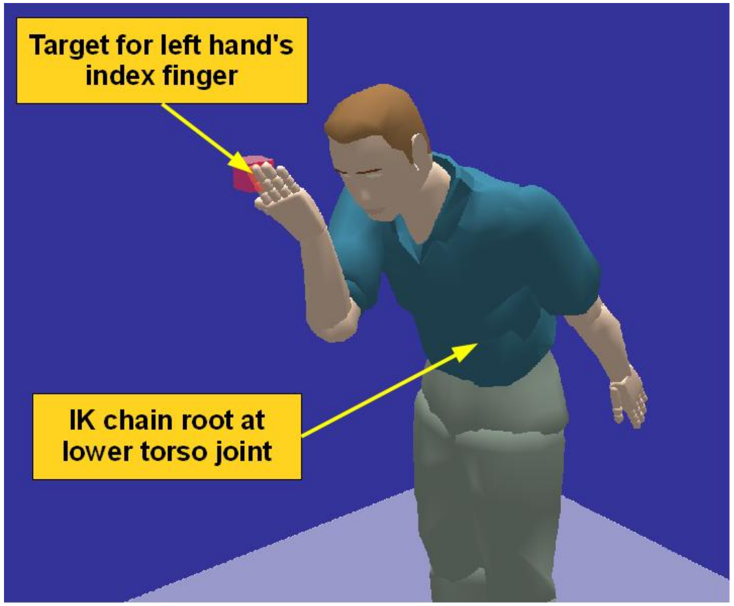


Comfort-based Inverse Kinematics

- What if the probability of selecting a “more” proper IK joint DoF angle was increased, compared to the probabilities of the other candidate angles? The result would be a posture that is more realistic and more comfortable.
- Thus, the proposed IK algorithm selects an angle with probability density based on an gaussian distribution: The gaussian center is on the most comfortable / neutral angle (as they have computed from postural analysis techniques, such as the RULA, REBA and LUBA).
- In addition to this several penalty factors are applied when the solution is moving away from the joint’s comfort center.

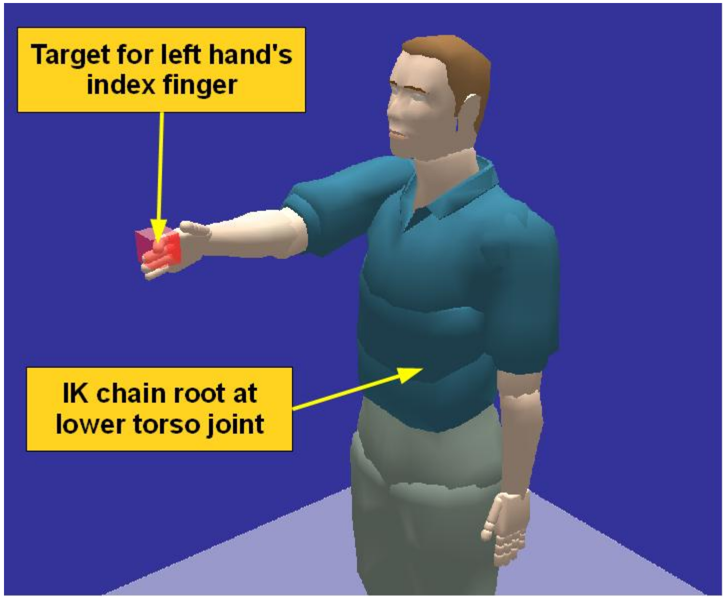


Simple and Comfort-based IK comparison



Simple IK

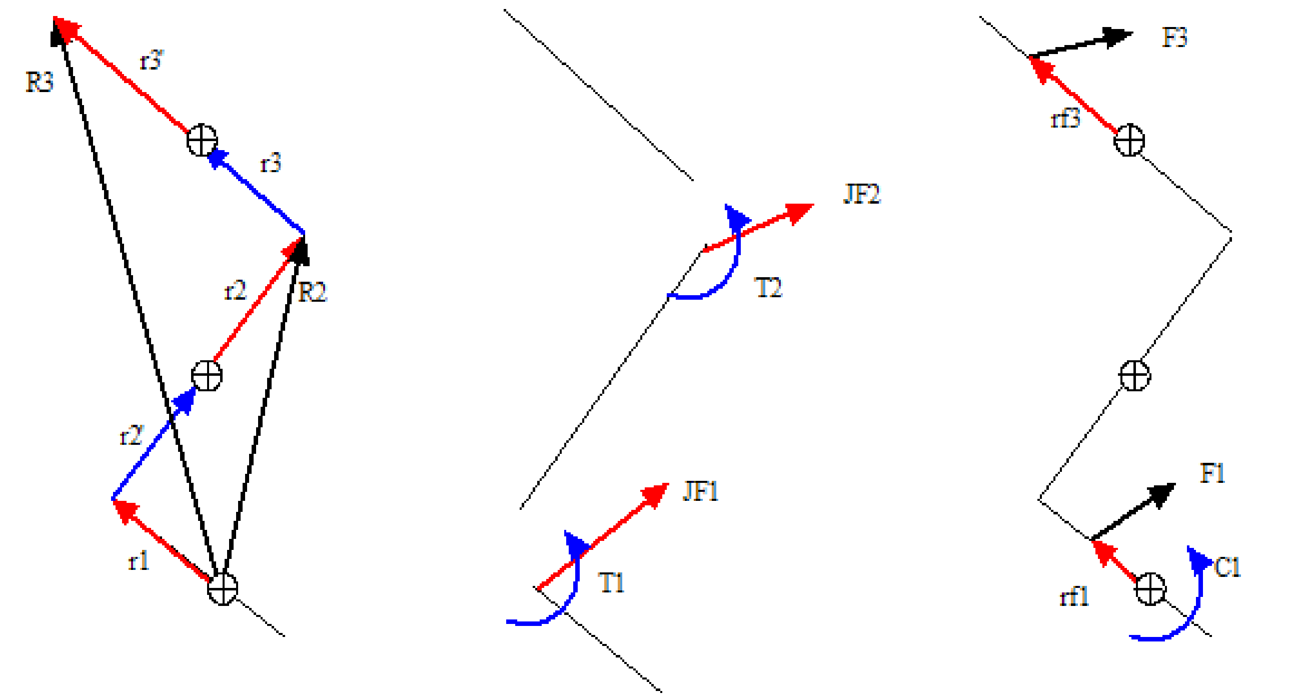
The resulted posture is sometimes unrealistic. This phenomenon increases when the number of possible IK solutions is infinite.



Comfort-based IK

The probability of getting a more comfortable and realistic posture is highly increased compared to the other possible solutions.

Inverse Dynamics



definition of vectors

⊕ = location of the center of mass

proximal forces and torques due to intertia and joints

External Forces and Couples

$$\mathbf{F}_{proximal} = \sum_{i=1}^{n} m_i(\mathbf{a}_i + \mathbf{g}) + \sum_{j=1}^{q} \mathbf{F}_q$$

m_i = mass of segment i

a_i = acceleration of segment i

n= the number of distal segments connected in chain

q= the number of external forces

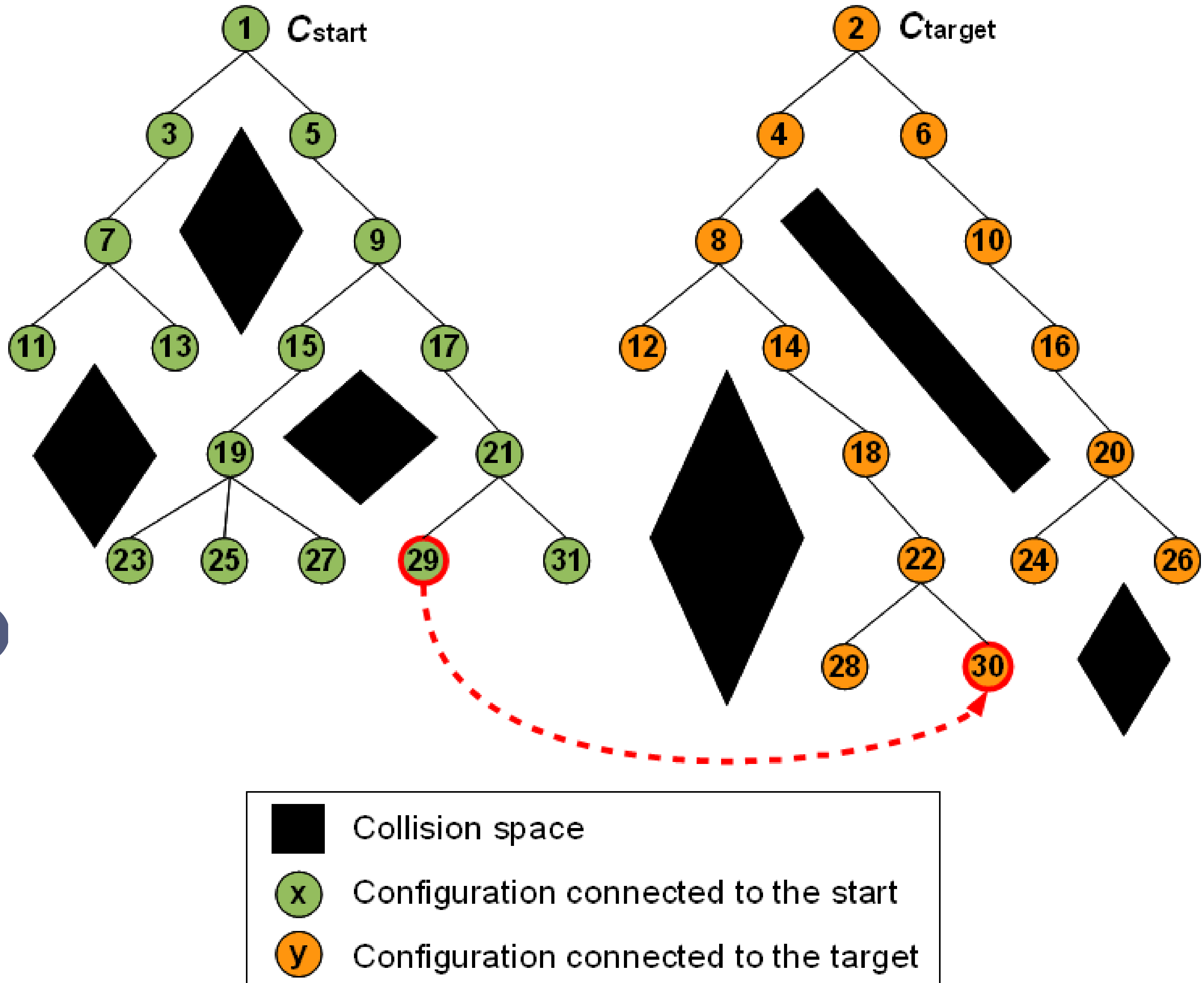
F_q=applied external forces

The forces will be converted to torques - body joints can only rotate!

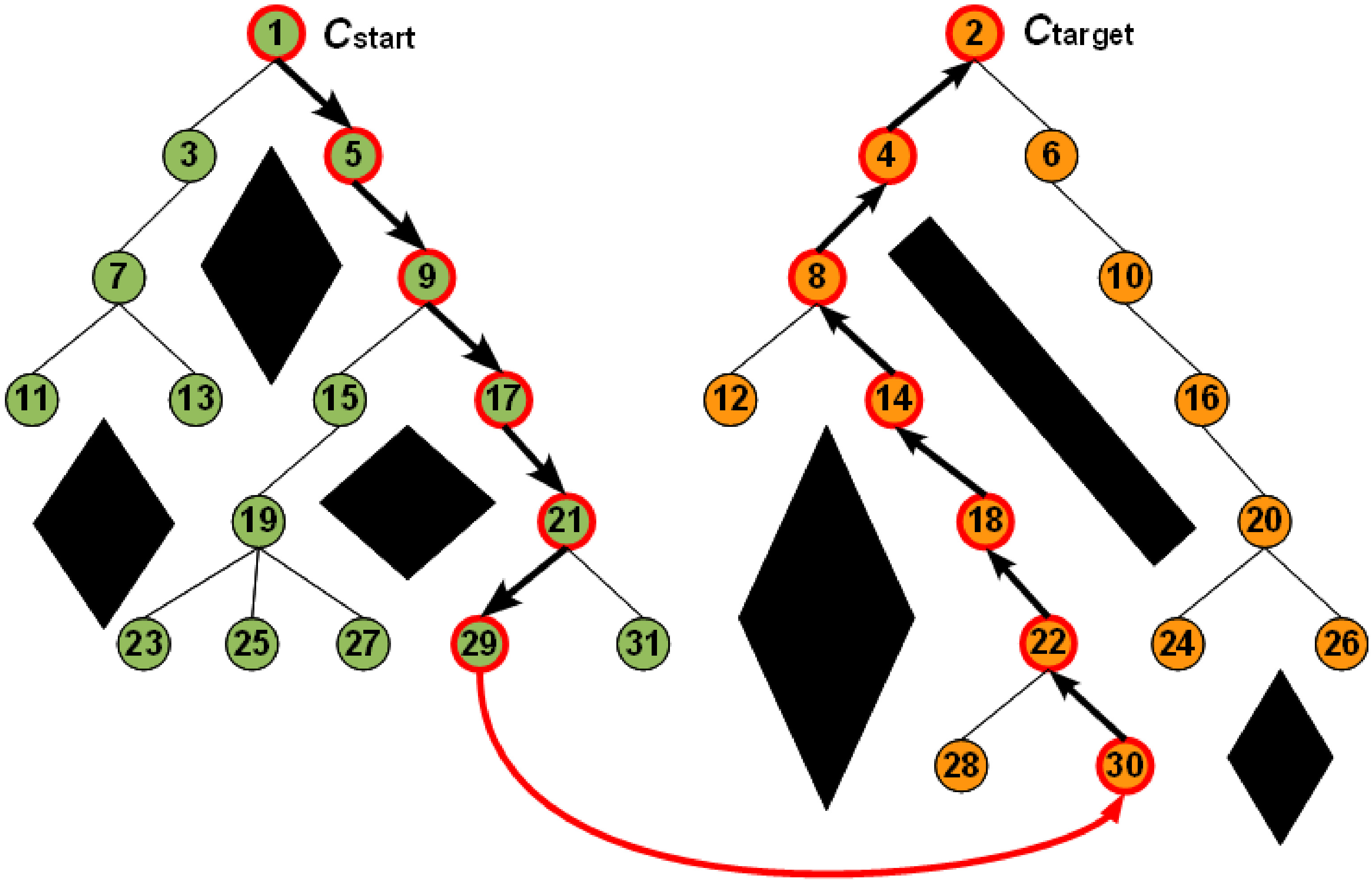
Motion planning

- The simulated avatar must not collide with the scene while interacting with them. Need for special collision avoidance compensation.
- Motion planning algorithm based on Random Rapidly Exploring Trees. Two-RRET method provides both efficiency and quality.
- Inputs: a scene collision space description and two configurations (under the term “configuration” it is meant the set of all the avatar state parameters , i.e. joint angles, positions in space, etc.):
  - The start configuration $\boldsymbol{C}_{start}$, i.e. the avatar’s current state.
  - A target configuration $\boldsymbol{C}_{target}$, i.e. the avatar’s target state.
- Two trees are generated and $\boldsymbol{C}_{start}$,$\boldsymbol{C}_{target}$ are the roots of them
- The trees are expanded in a pseudo-random manner, by selecting a current tree node $\boldsymbol{C}_{current}$ and computing a new configuration $\boldsymbol{C}_{new}$ that is very close to it. If the transition $\boldsymbol{C}_{current} \rightarrow \boldsymbol{C}_{new}$ is feasible, the planner connects them.
- Every time a tree expands, the planner checks if the $\boldsymbol{C}_{new}$ can connect to any of the other tree’s nodes, and if true, the trees are connected and the motion planner has found its solution.

Motion planning



Motion planning



Collision space

x Configuration connected to the start

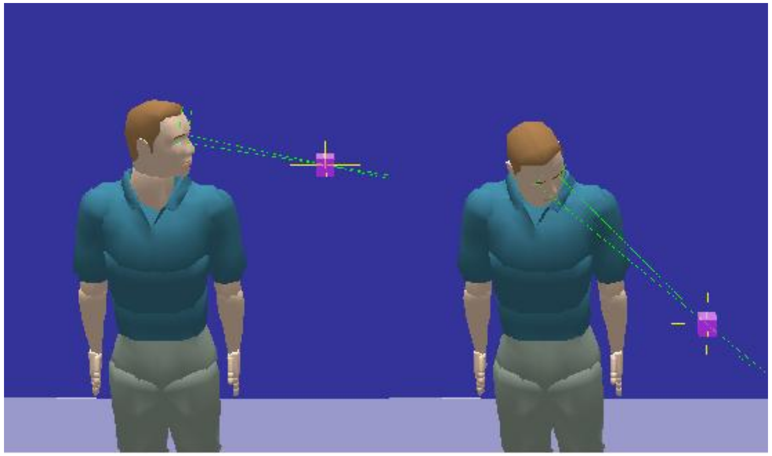
y Configuration connected to the target

Motion planning

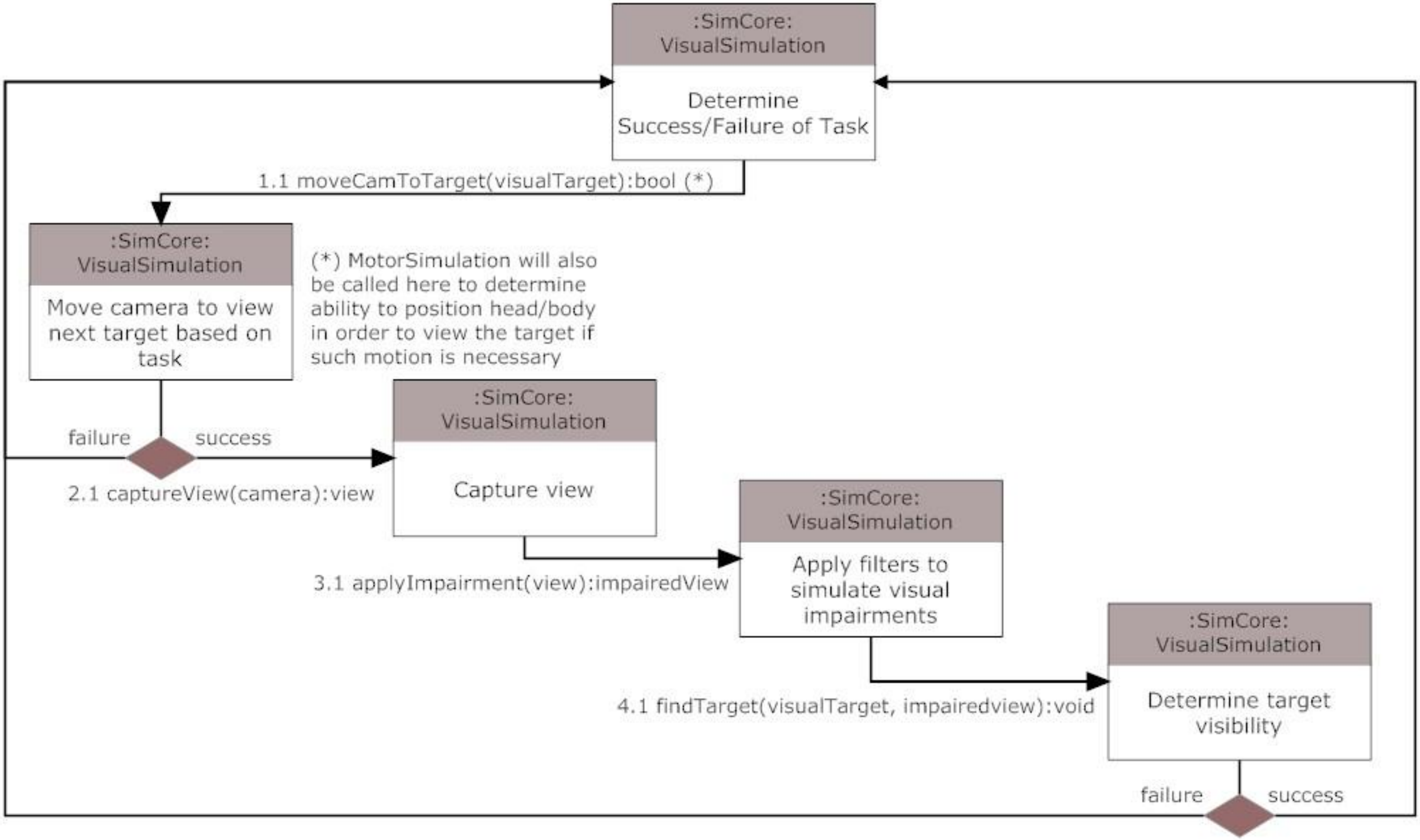
- After the RRET solution is provided, a low pass filtering is applied to the motion curves in order to make the movement more realistic.
- After a predefined number of repetitions if a solution has not be found, the algorithm stops and reports that the transition from the start configuration, $\boldsymbol{C}_{start}$, to the target configuration, $\boldsymbol{C}_{target}$, is not possible.
- The motion planner has been tested also with only one tree, but the solution could not computed as fast as the two trees.
- More than two trees could also be used – in that case, however, too much resources would be consumed by the system and the overall gain is not worth it.
- Graph based methods have also been used (instead of trees), producing overall more realistic results – however they needed too much time (a rank larger comparing to trees) to be built and could not handle properly the on-the-fly scene changes.

Vision capabilities simulation

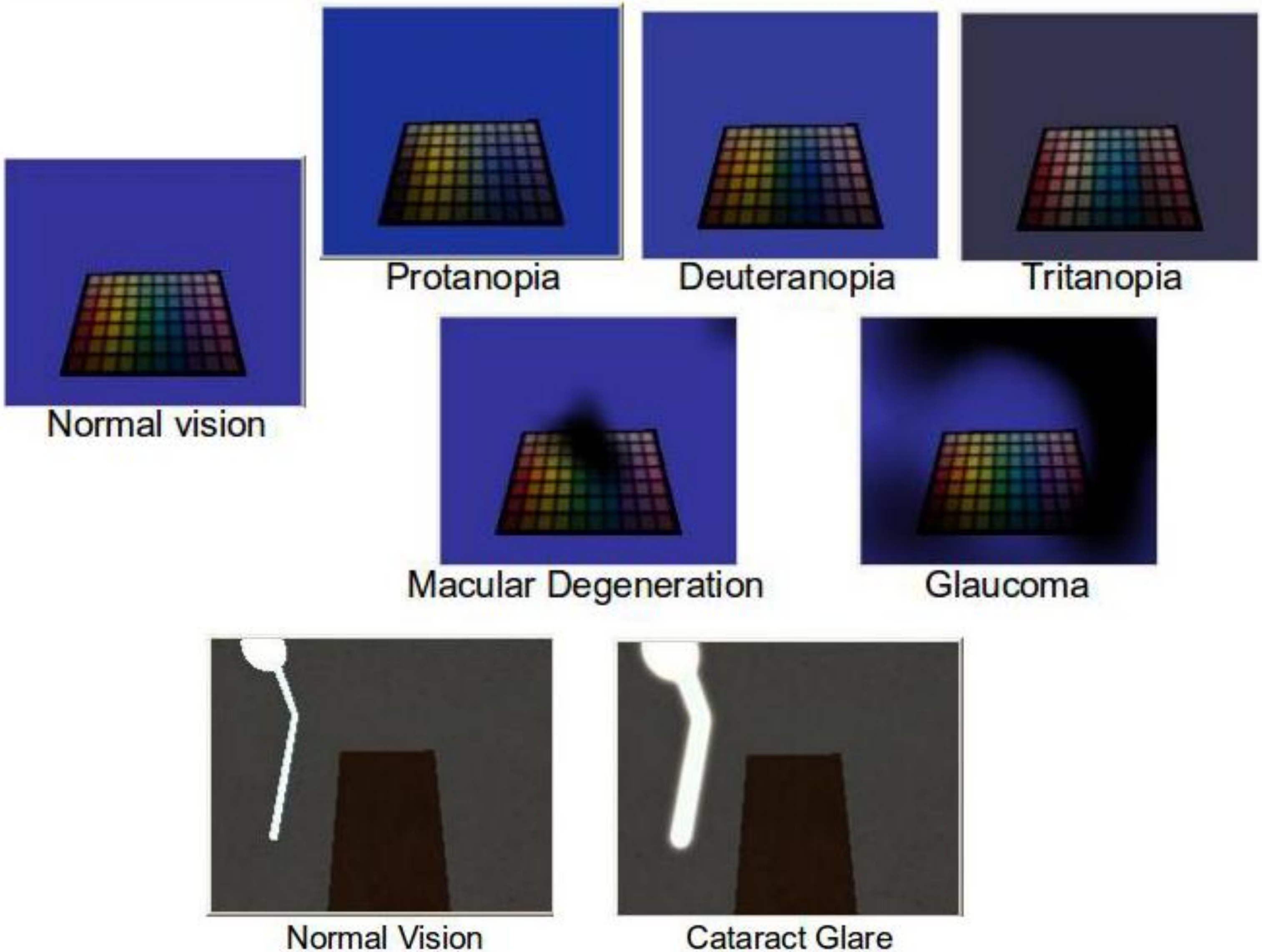
- Several algorithms have been implemented in order to filter the input world images, based on the virtual user’s vision impairment.
- The impairments supported are:
  - Protanopia, Deuteranopia, Tritanopia
  - Macular Degeneration
  - Glaucoma
  - Cataract
- All filters are applied at each frame.
- Head and eye movement in order to track the task target and shows the designer the avatar’s line of sight.



Vision capabilities simulation



Vision capabilities simulation

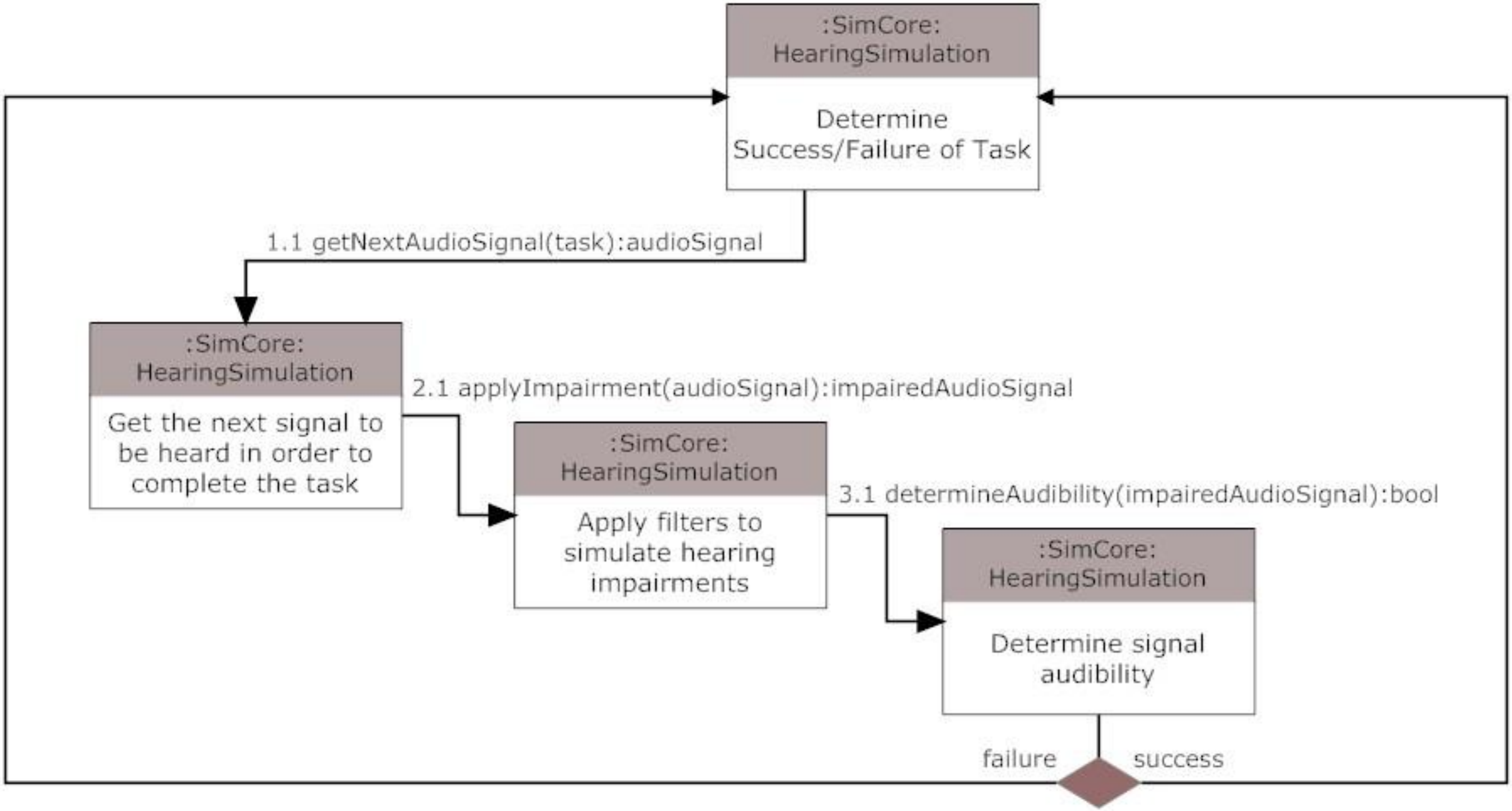


Auditory capabilities simulation

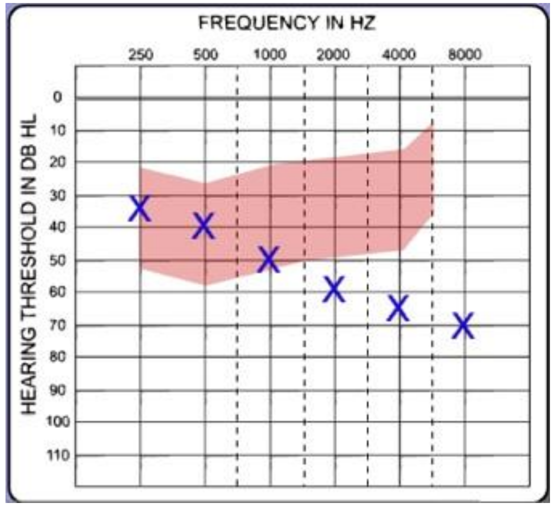
- Concerning the hearing capabilities simulation:
  - Real time filtering of multi-channel and multi-source sound.
  - The produced filters are based on the provided virtual user audiogram and their purpose is to attenuate the signal in predefined frequency bands.
  - Several impairments are supported: Otitis, Otosclerosis, Presbycusis, Noise Induced Hearing Loss, etc.
- Concerning the speech capabilities simulation:
  - Initial steps on implementing basic text to speech tools have been made (variety of voices, languages).

Hearing Simulation Video

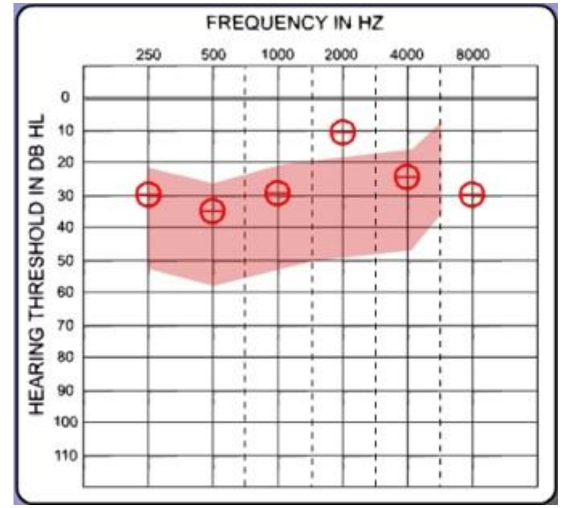
Auditory capabilities simulation



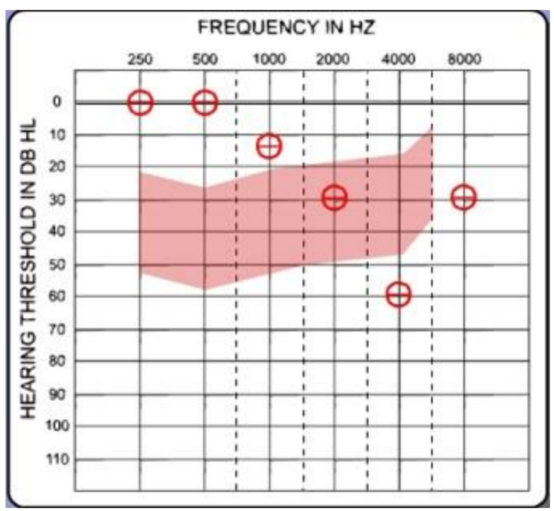
Hearing impairments' audiograms



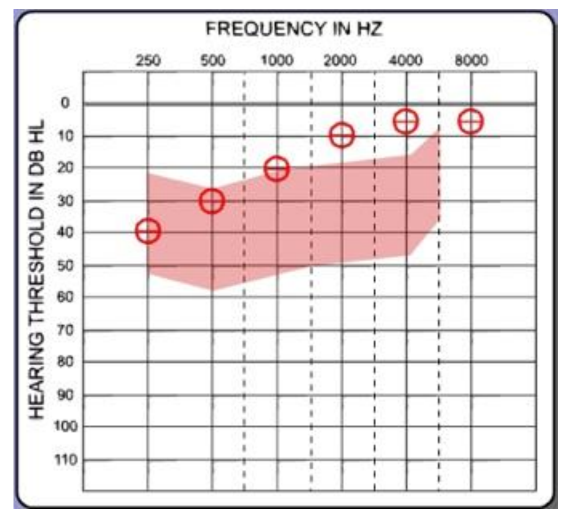
Presbycusis - age related



Otitis



Noise induced hearing loss

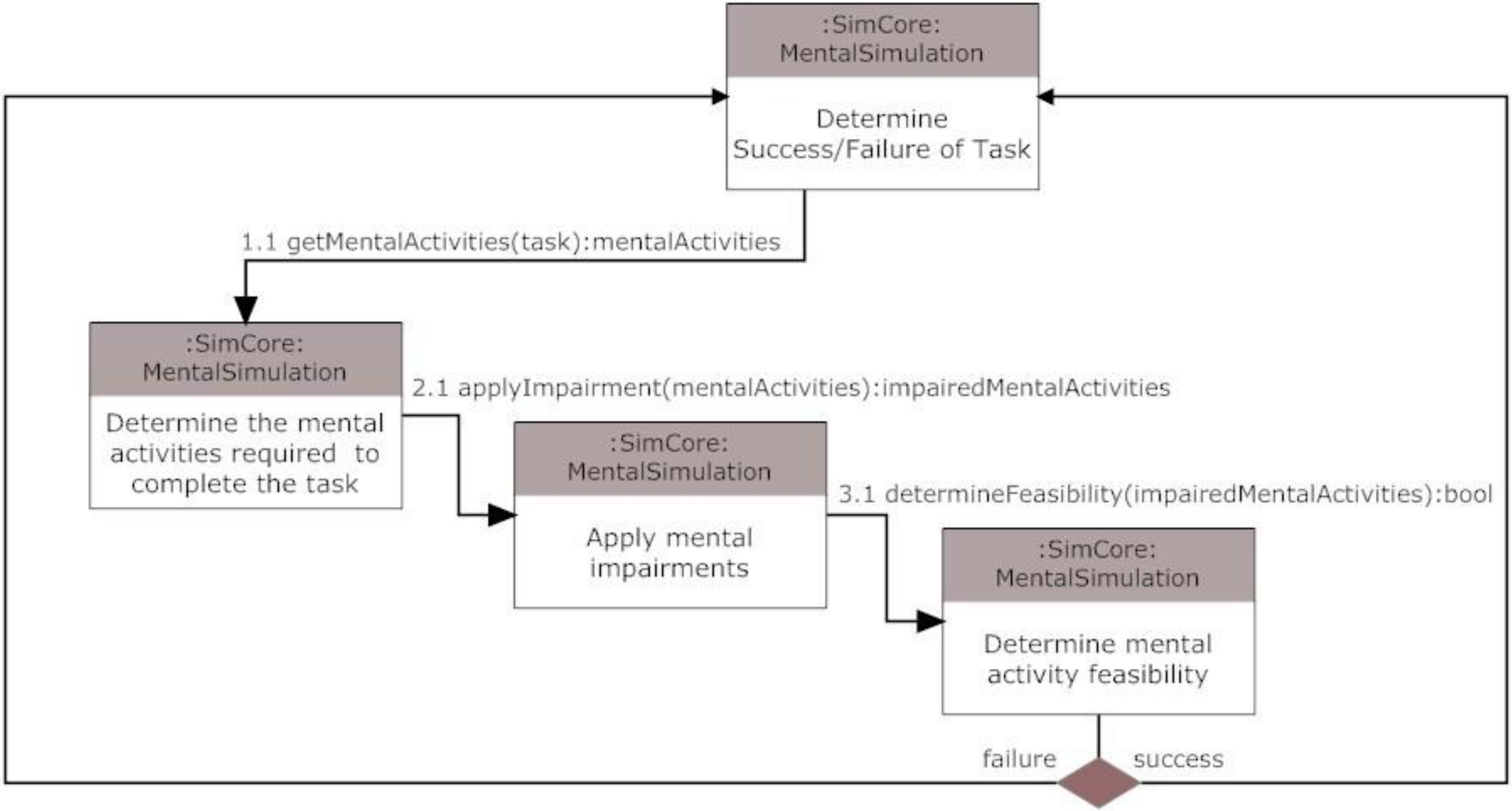


Otosclerosis

Cognitive / Behavioural capabilities simulation

- For the time being, the virtual user's cognitive capabilities are simulated as a context awareness interpretation.
- This means that depending on the current avatar's context state, several parameters from the domains of motor, vision, auditory are affected.
- For example, if the simulated user model is feeling tired, then its strength capabilities are reduced (by filtering and lowering the maximum torque that can be generated at each of the bone-joints).

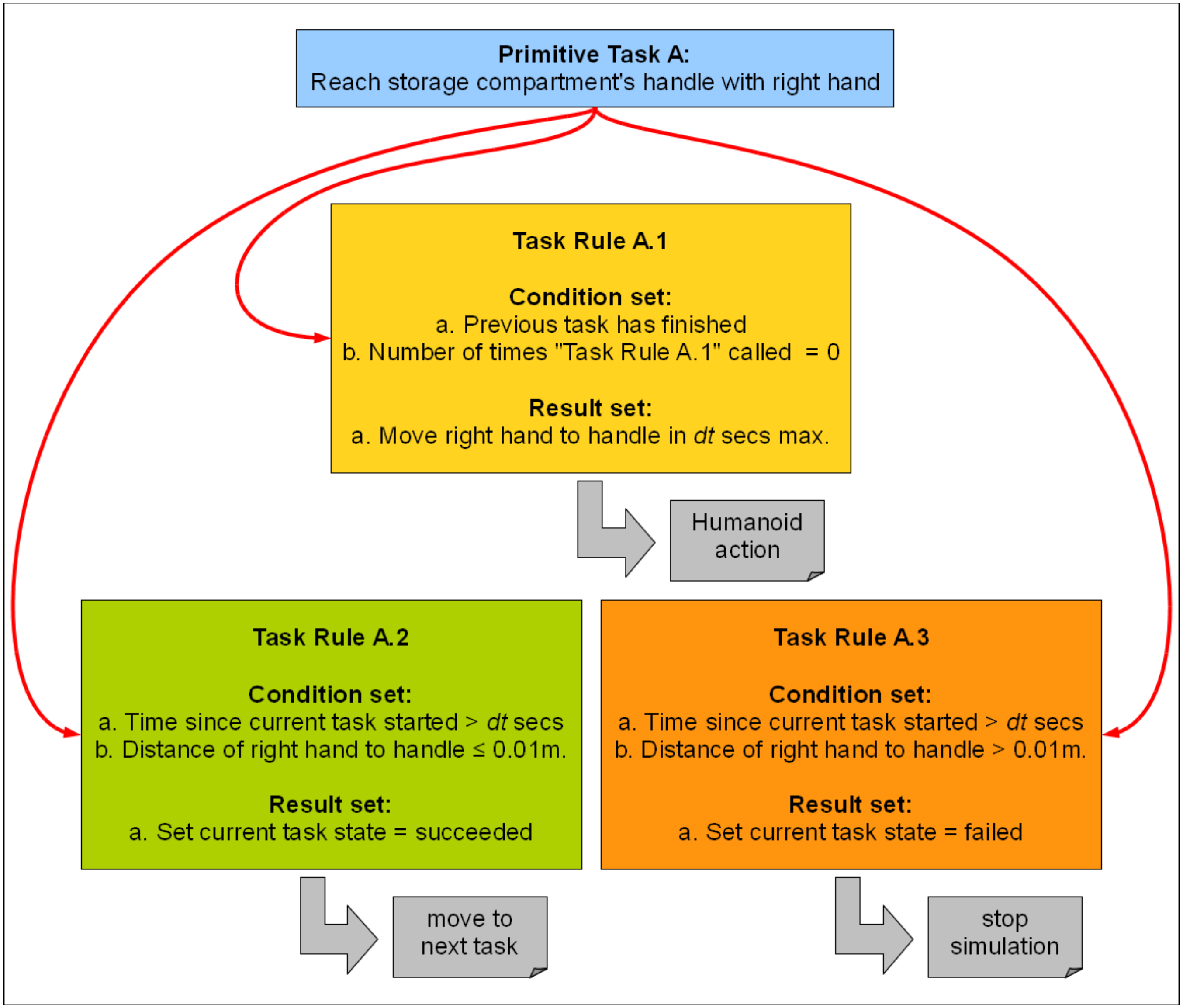
Cognitive / Behavioural capabilities simulation



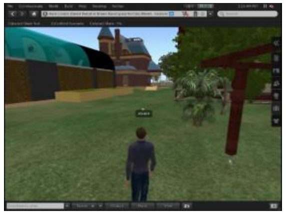
Task Management: Task Manager Module

- The task manager module is responsible for managing the actions of the humanoid in order to provide a solution to the given complex task.
- After splitting a complex task to a series of primitive tasks, like “reach”, “grasp”, “pull”, etc., the task manager instructs the humanoid model to perform a series of specific movements in order to accomplish them.
- Each primitive task can have a set of rules that are checked at each timestep. Each rule has two main parts:
  - The condition part and
  - The result part.
- When a condition is met, the rule's result part is applied.

Task Rule example



Experimental Results

Application:	Automotive “Pull handbrake”	Workplace “Open drawer”	Infotainment
Users:	Normal & Elderly (limited strength capabilities).	Normal & user with Rheumatoid Arthritis (limited shoulder RoM).	Several users having vision and hearing impairments.
Video example:			
Result:	Normal user successes, while elderly user fails (cannot pull).	Normal user successes, while user with R.A. fails (cannot reach handle).	Some of the world information is not accessible by all users.

Conclusions & Future Work

- The presented work proposes a open framework that performs automatic simulated accessibility testing of designs in virtual environments using virtual user models.

- The great importance of such a framework lies to the fact that it can simulate various impairments of various fields (motor, vision, hearing, speech, cognitive), resulting to an increased prestige to the fidelity of the accessibility results.

- Several features of the simulation framework need further investigation and improvement, such as the speech and cognitive simulation processes. However, even in its current state, the framework provides a valuable design prototype accessibility test tool in a great variety of prototyping domains.

Thank you!

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