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St Petersburg
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Towards Mitigating the Eye Gaze Tracking Uncertainty in Virtual Reality

This study is supported by the research grant
No. ID75288744 from Saint Petersburg University,
"Text processing in L1 and L2: Experimental study
with eye-tracking, visual analytics and virtual reality
technologies"

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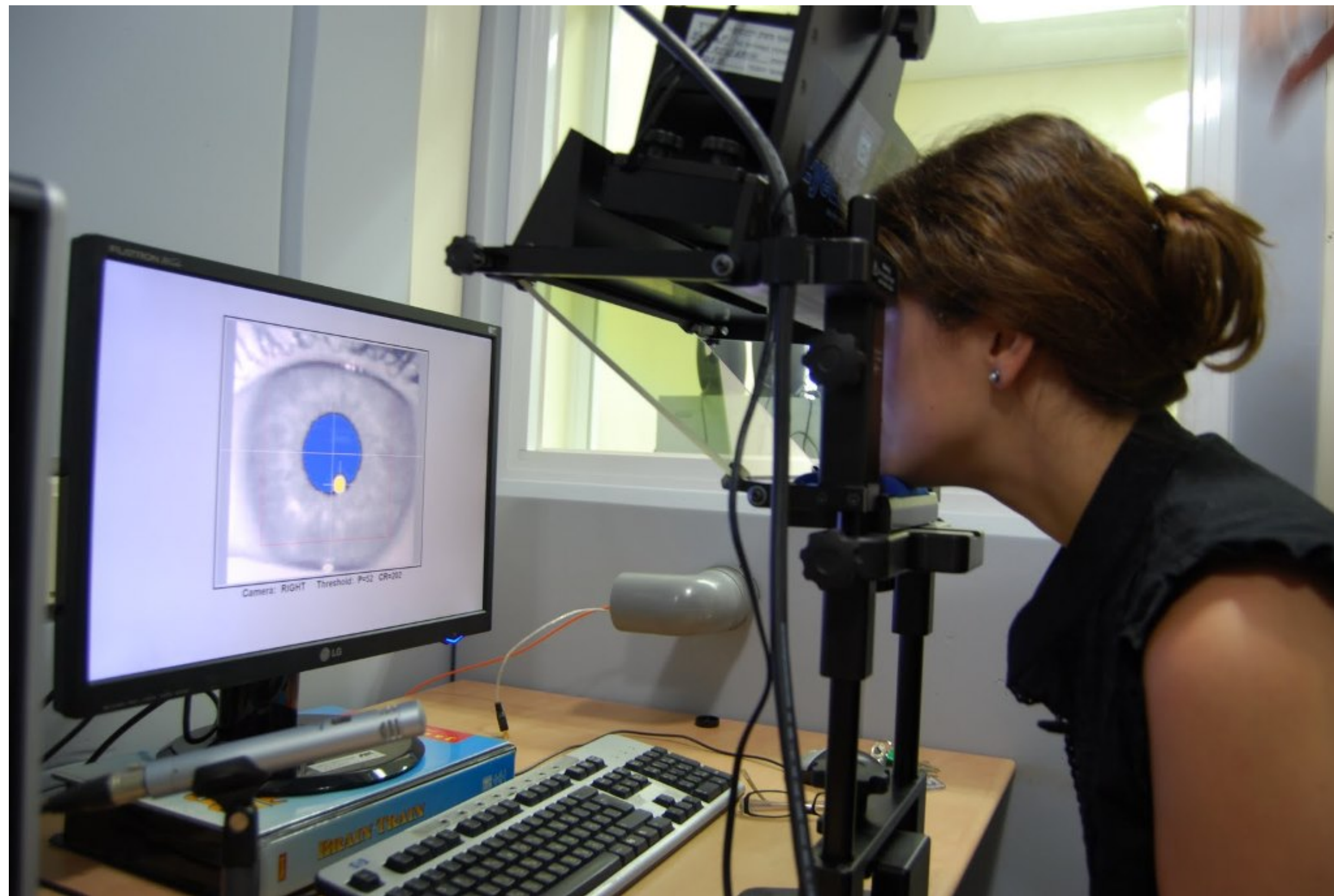
Svetlana Chuprina²,
chuprinass@inbox.ru

Methodology of studying the information perception based on tracking the eye gaze movements



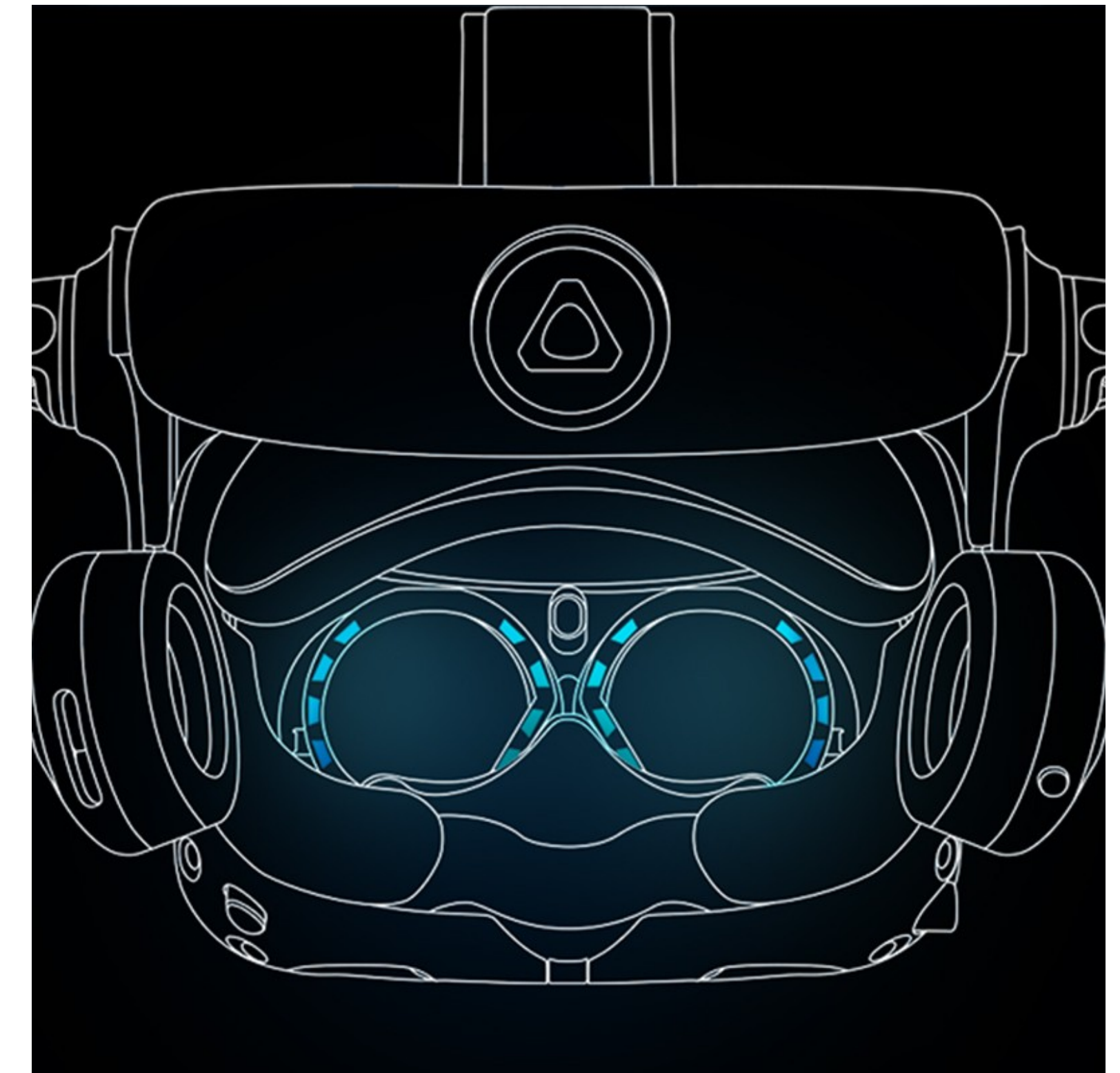
(Holmqvist et al., 2017)

100+ years evolution of devices, algorithms and methods



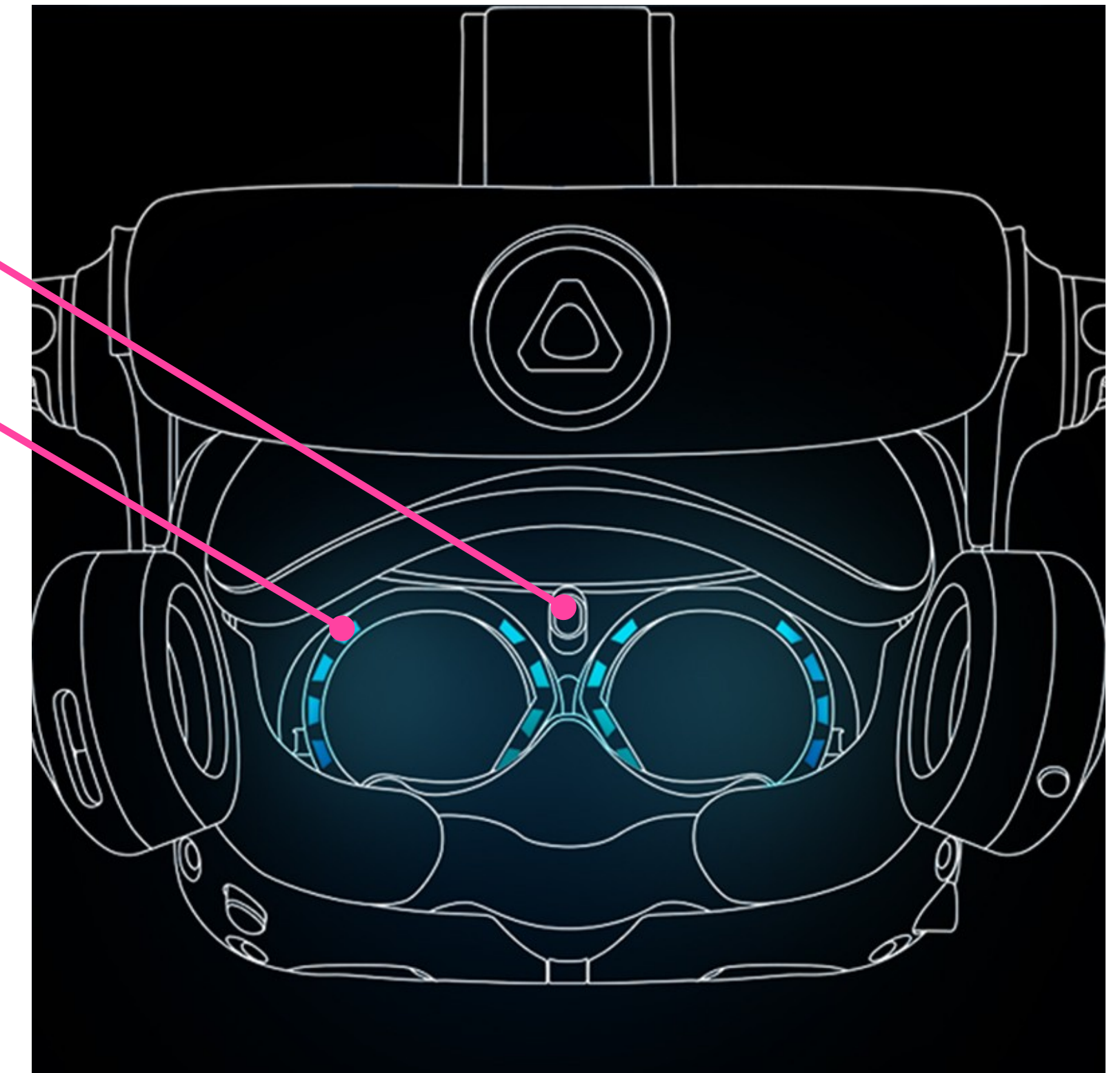
(Shehu et al., 2021)

Recently, eye trackers are available in VR head-mounted displays

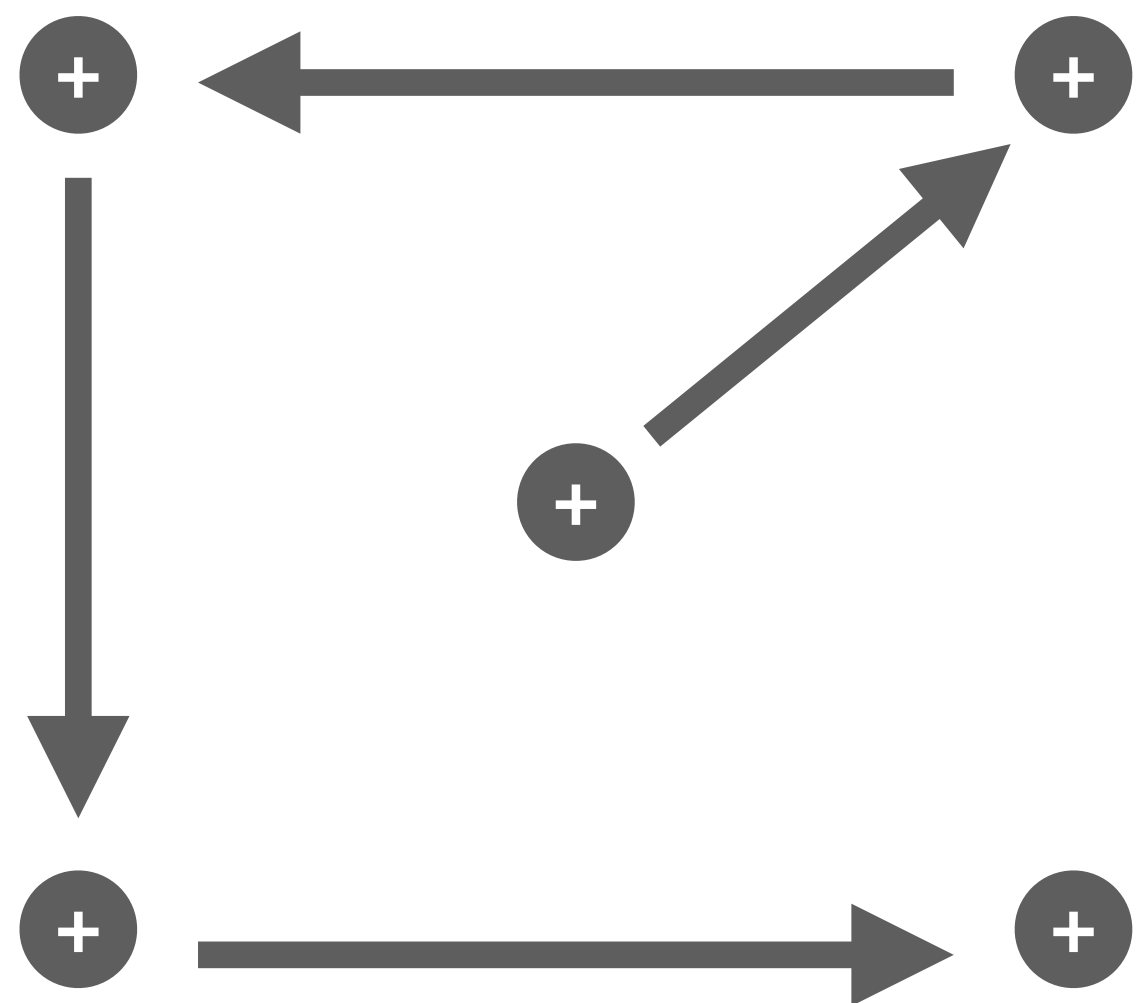


(Clay et al., 2019; Iacobi, 2018)

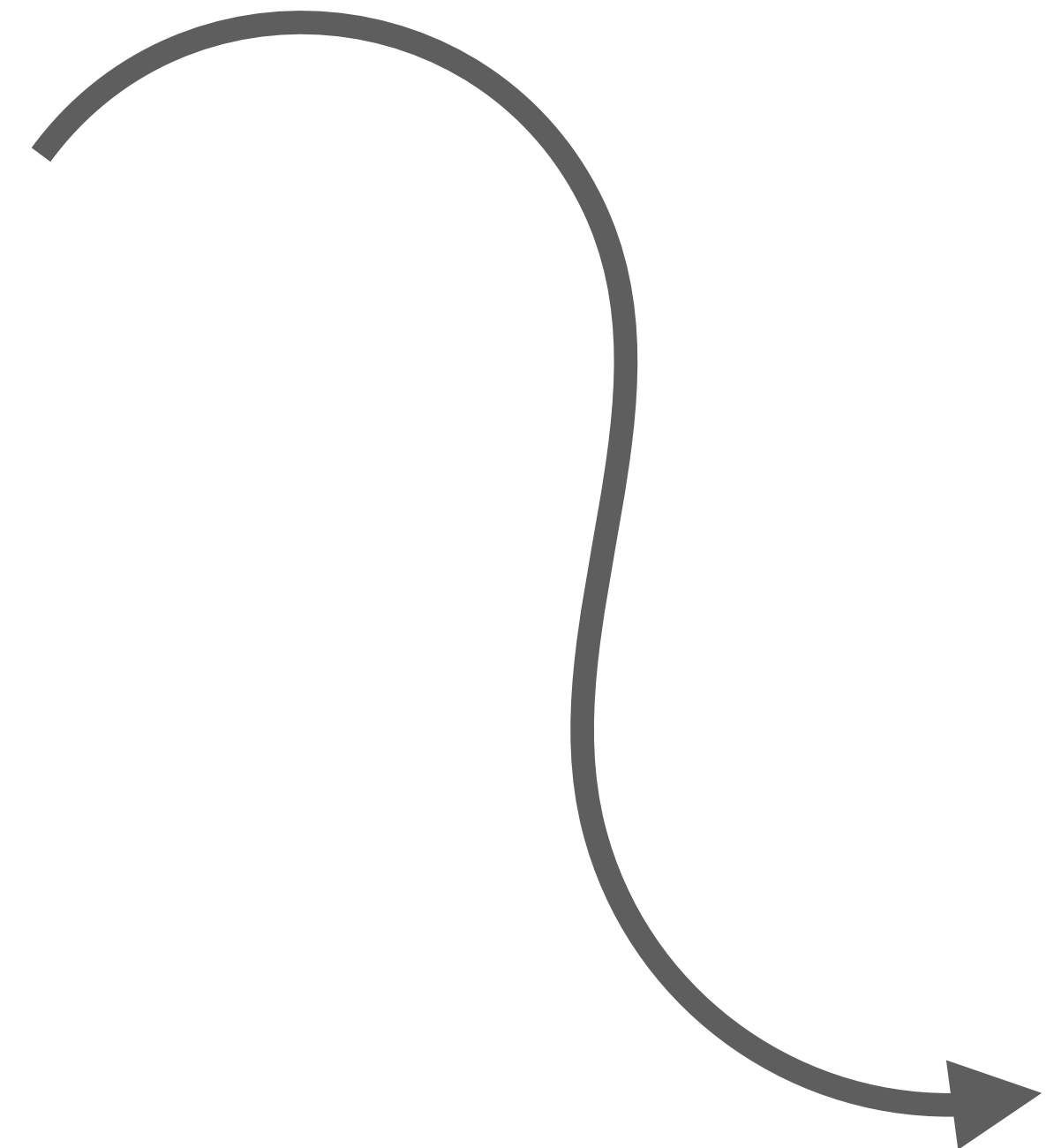
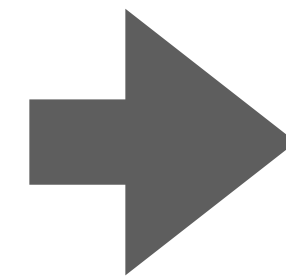
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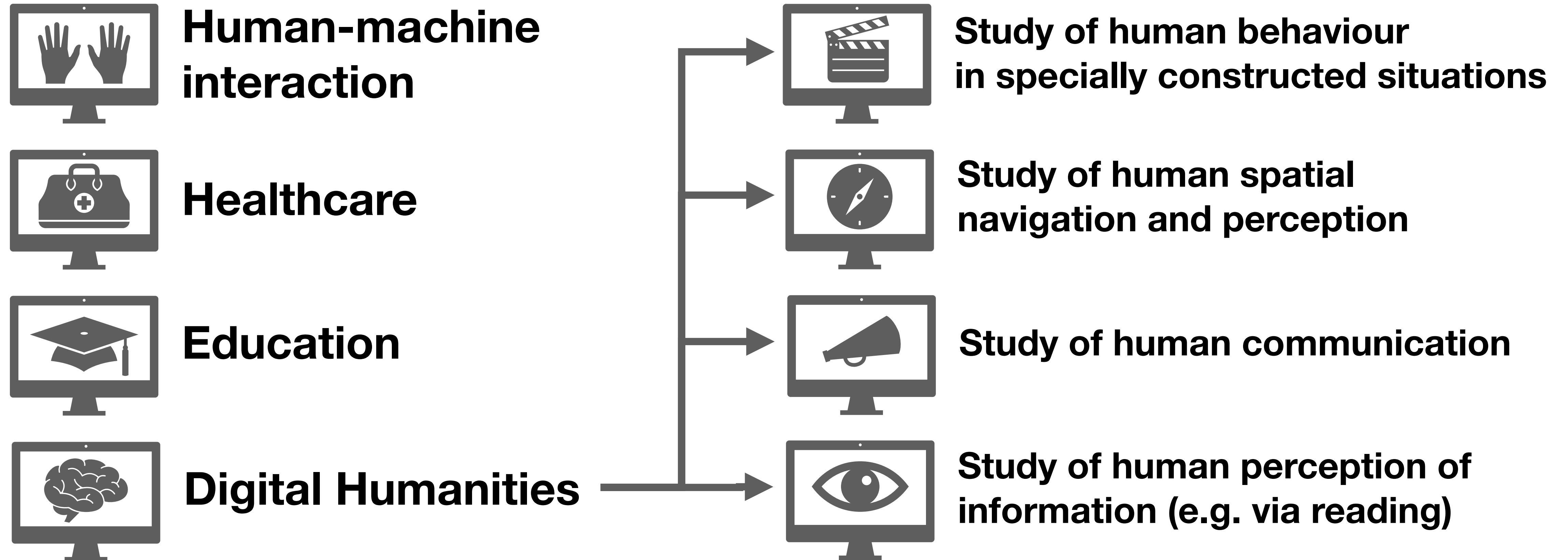
(Clay et al., 2019; Iacobi, 2018)



Calibration

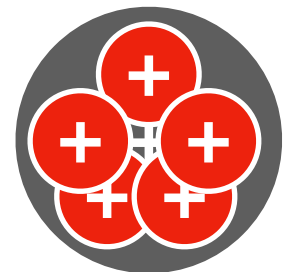


Tracking

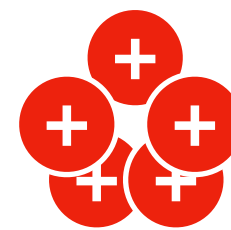


(Skulmowski et al. 2014; Sonntag et al. 2015; Lohr et al. 2019; Jogeshwar et al. 2020; Imaoka et al. 2020; Mirault et al. 2020; Ryabinin et al. 2021)

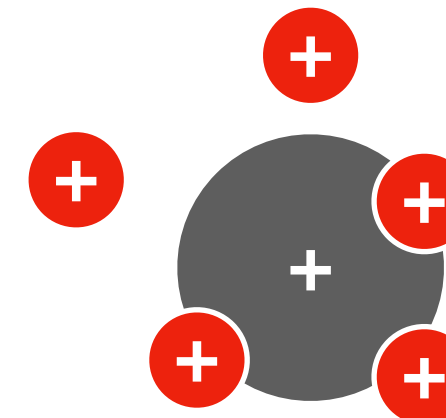
Eye trackers built in VR head-mounted displays have
low **sampling rate**
low **accuracy**
low **precision** } ➔ **Uncertainty** of gaze data



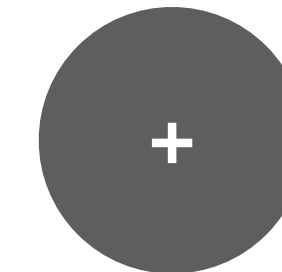
Good accuracy,
Good precision



Bad accuracy,
Good precision



Good accuracy,
Bad precision

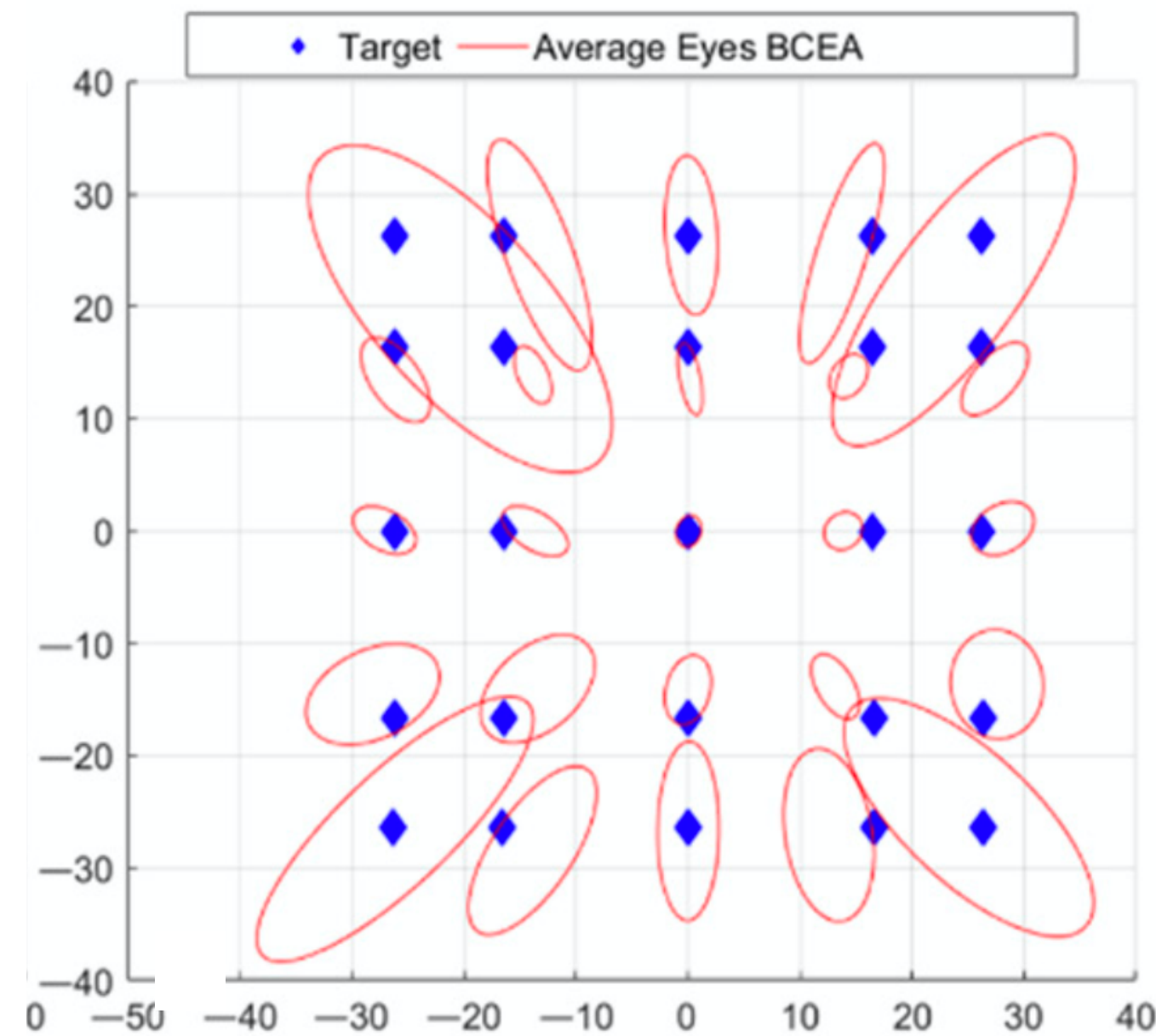


Bad accuracy
Bad precision

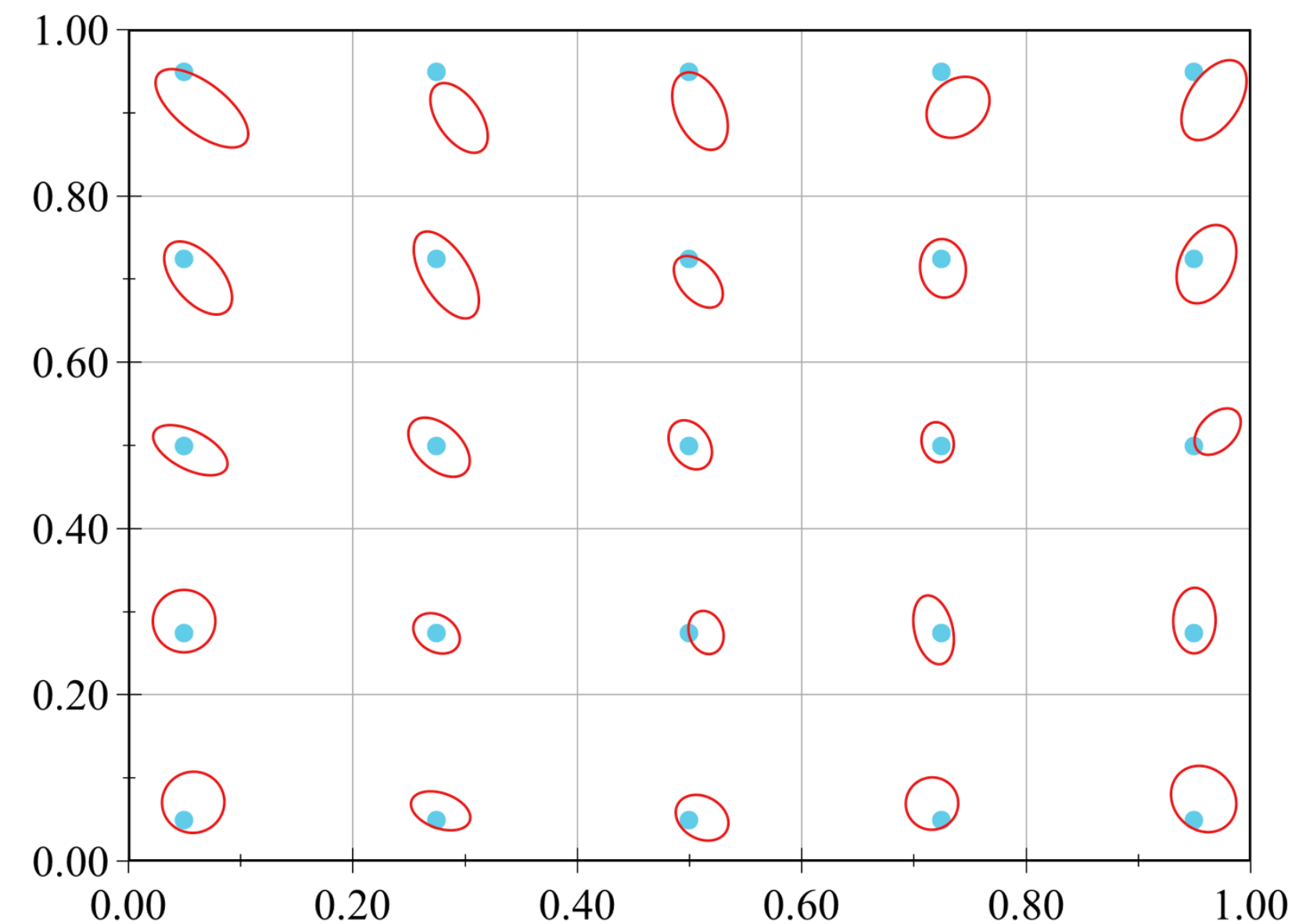
- ⊕ Ground-truth gaze position
- ⊕ Reported gaze position

(Binaee et al., 2016; Sipatchin et al., 2021; Drewes et al. 2019)

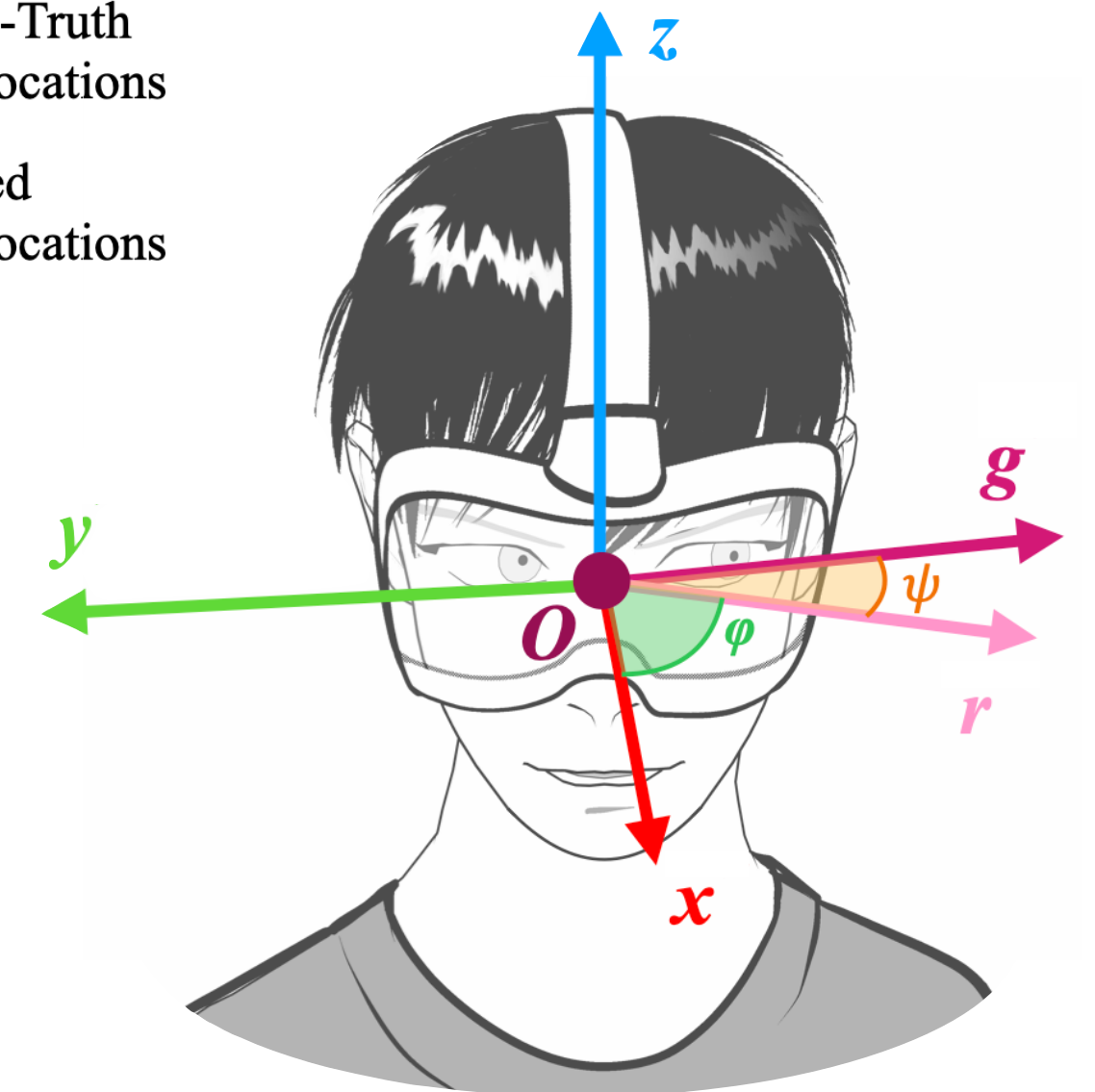
Accuracy and precision drop when the user looks to the side from their forward direction



(Sipatchin et al., 2021)

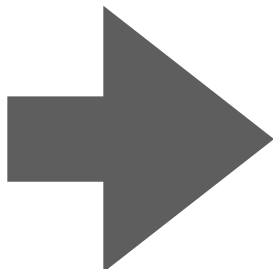
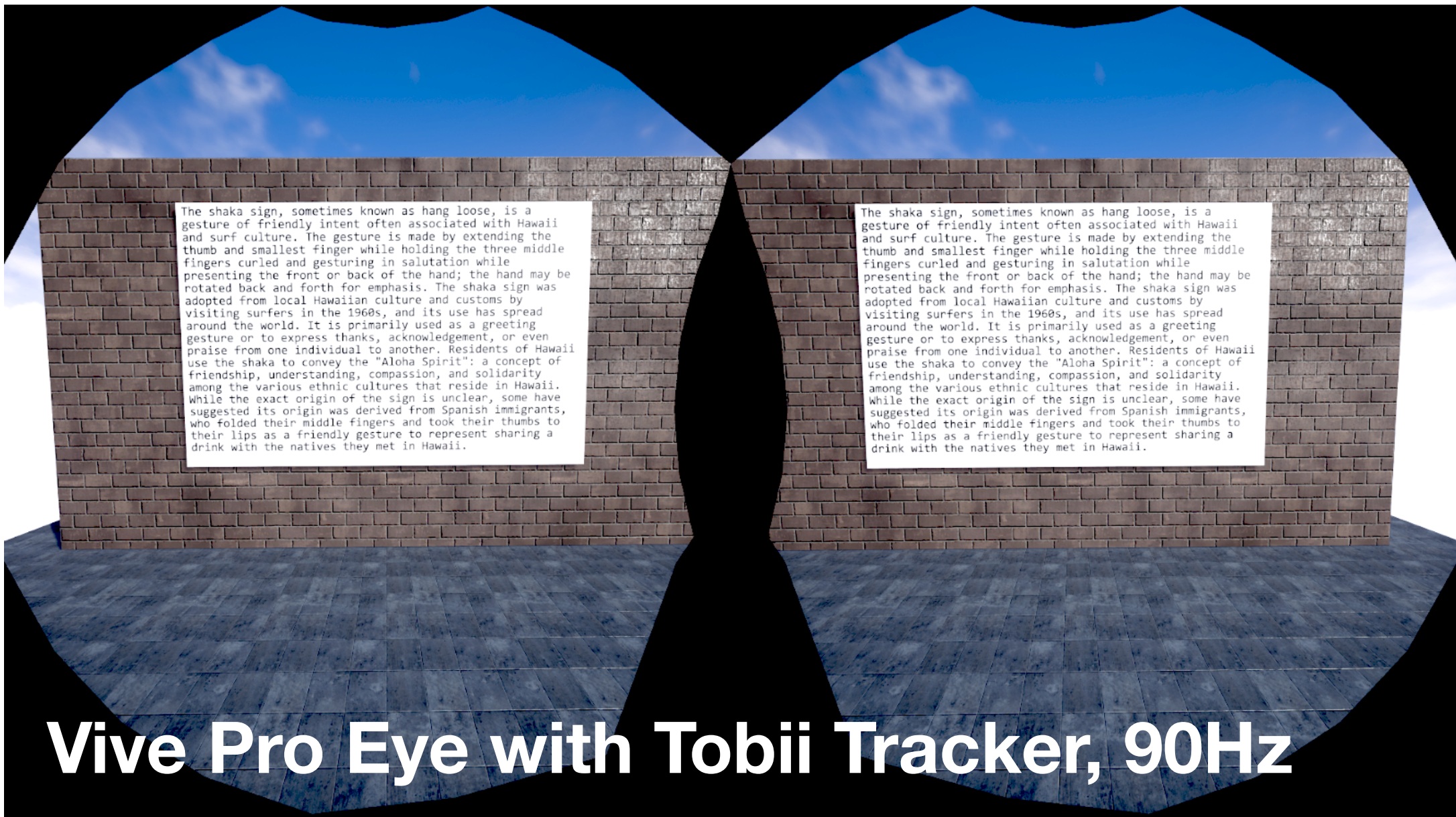


Ground-Truth
Gaze Locations
Reported
Gaze Locations



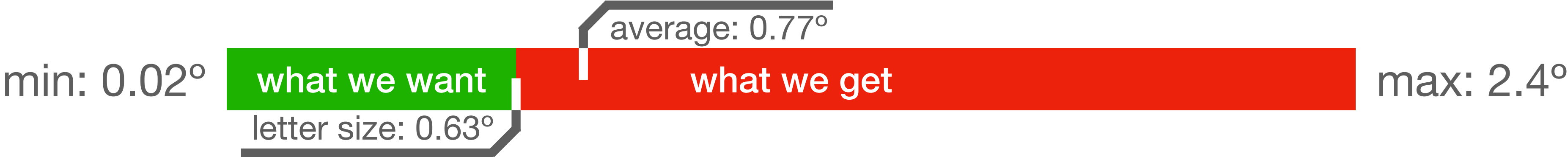
Our observations align with other research groups

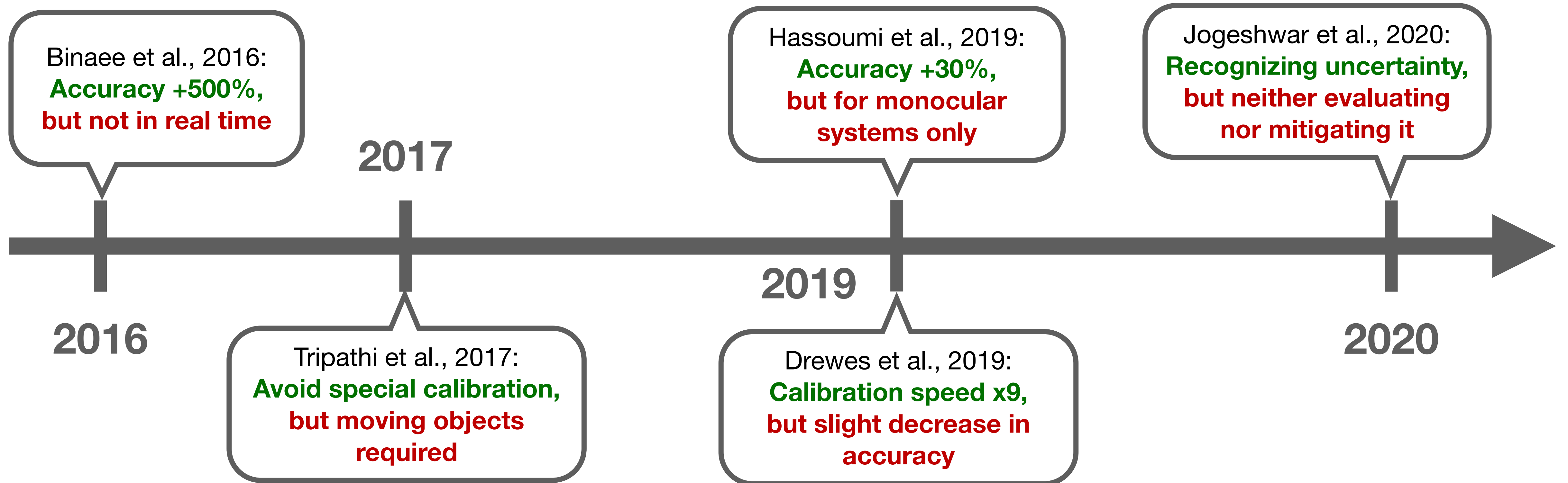
Our study of reading process

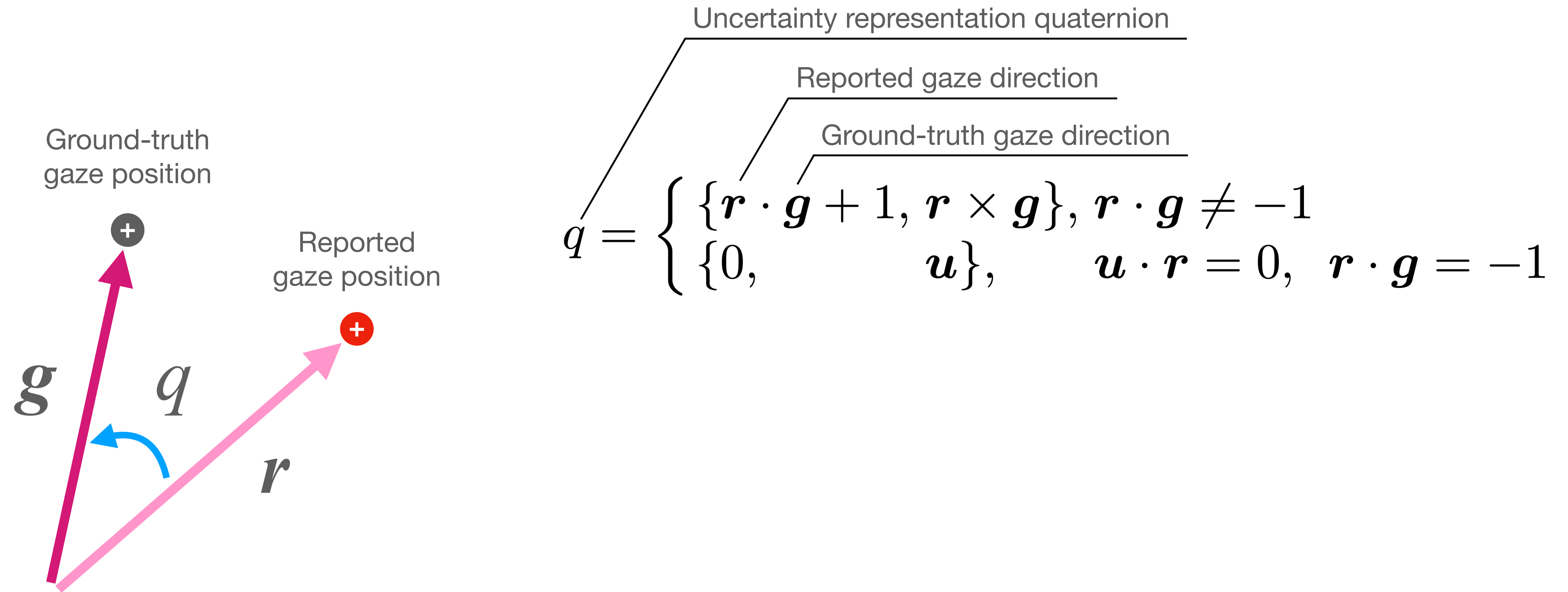


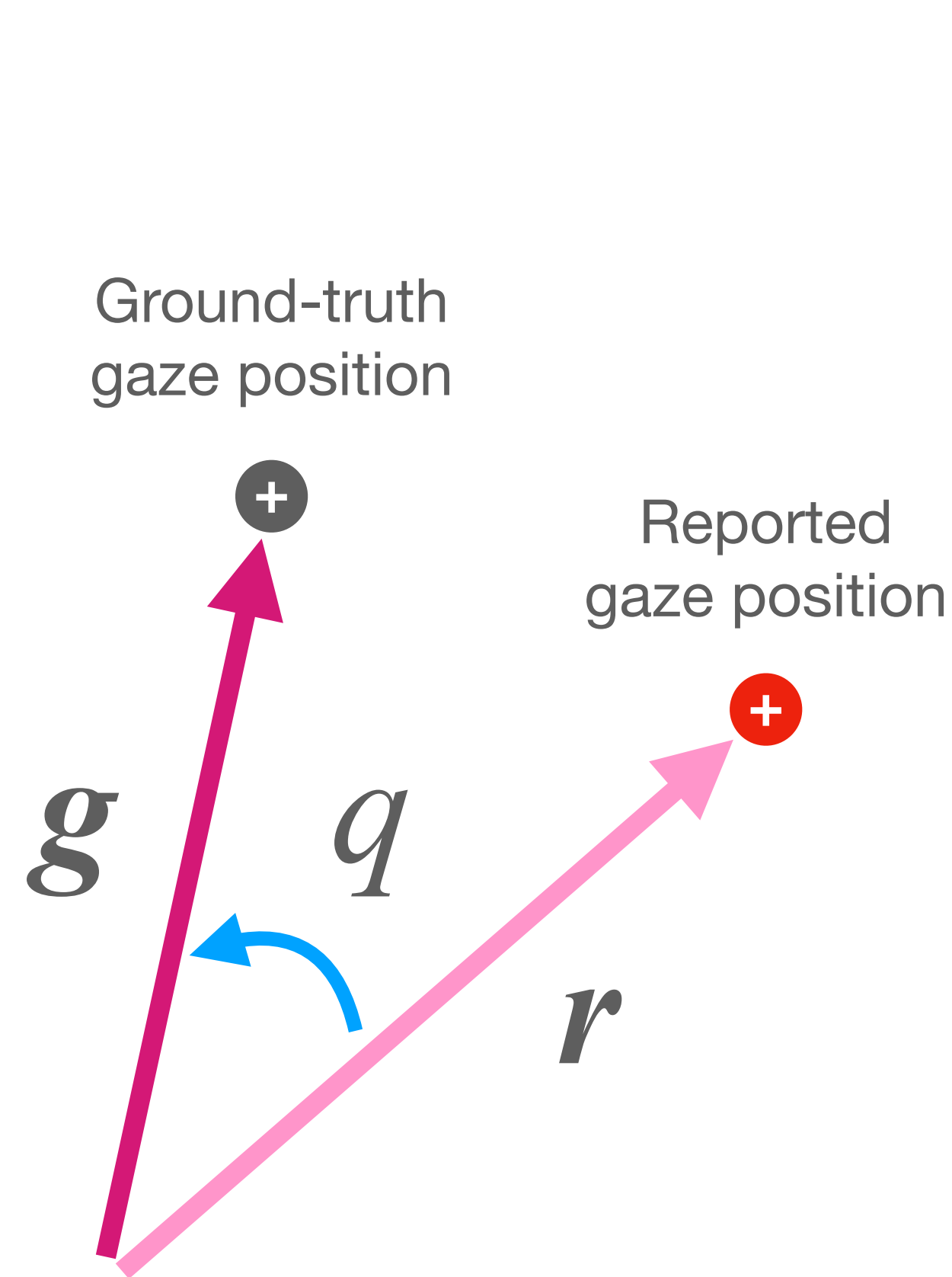
The shaka sign, sometimes known as hang loose, is a gesture of friendly intent often associated with Hawaii and surf culture. The gesture is made by extending the thumb and smallest finger while holding the three middle fingers curled and gesturing in salutation while presenting the front or back of the hand; the hand may be rotated back and forth for emphasis. The shaka sign was adopted from local Hawaiian culture and customs by visiting surfers in the 1960s, and its use has spread around the world. It is primarily used as a greeting gesture or to express thanks, acknowledgement, or even praise from one individual to another. Residents of Hawaii use the shaka to convey the "Aloha Spirit": a concept of friendship, understanding, compassion, and solidarity among the various ethnic cultures that reside in Hawaii. While the exact origin of the sign is unclear, some have suggested its origin was derived from Spanish immigrants, who folded their middle fingers and took their thumbs to their lips as a friendly gesture to represent sharing a drink with the natives they met in Hawaii.

Angular error of gaze positions









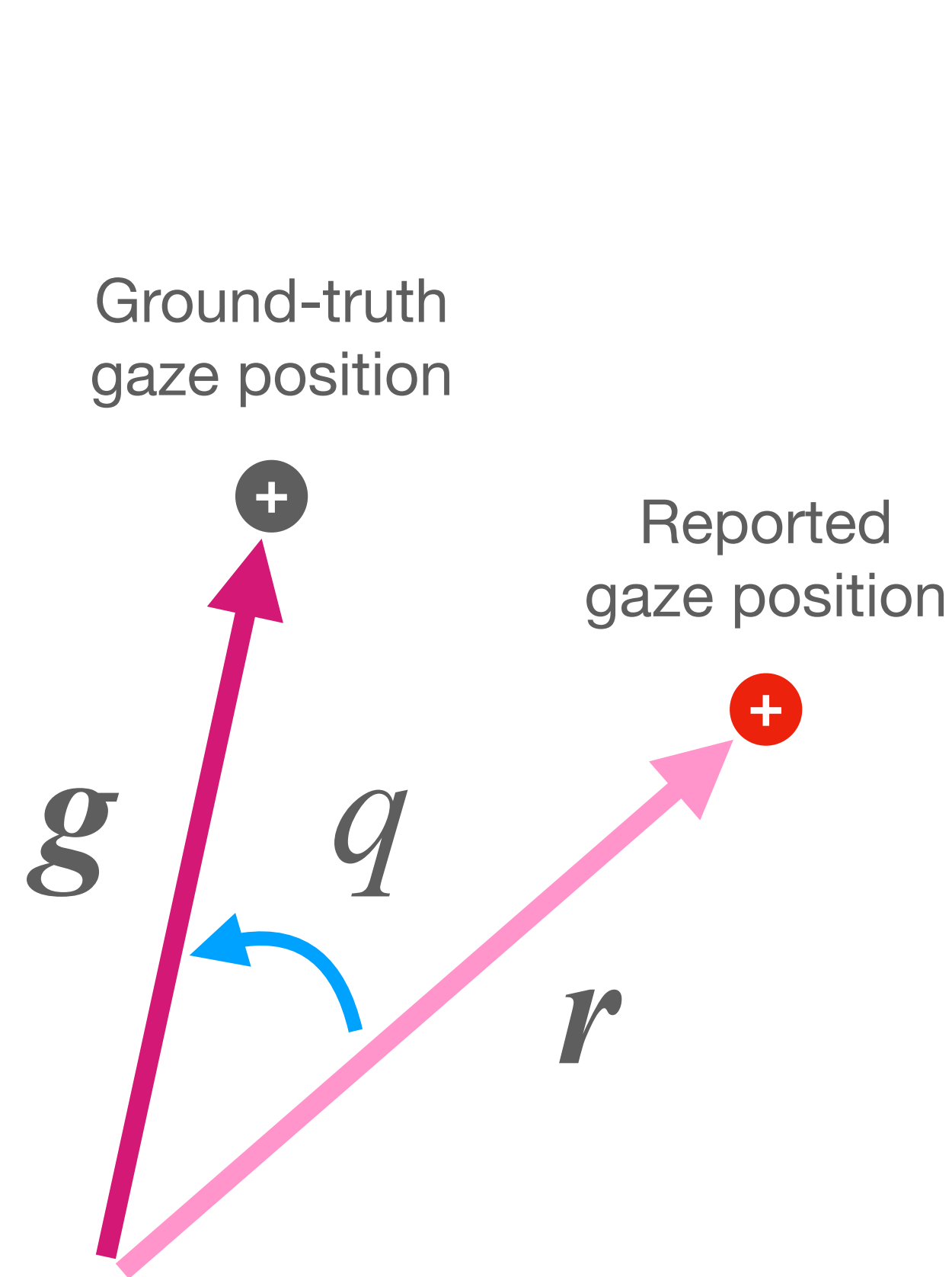
Uncertainty representation quaternion

Reported gaze direction

Ground-truth gaze direction

$$q = \begin{cases} \{r \cdot g + 1, r \times g\}, & r \cdot g \neq -1 \\ \{0, u\}, & u \cdot r = 0, \quad r \cdot g = -1 \end{cases}$$

$$q_{r \rightarrow g} = \frac{q}{|q|} \quad \text{— Quaternion normalization}$$



Uncertainty representation quaternion

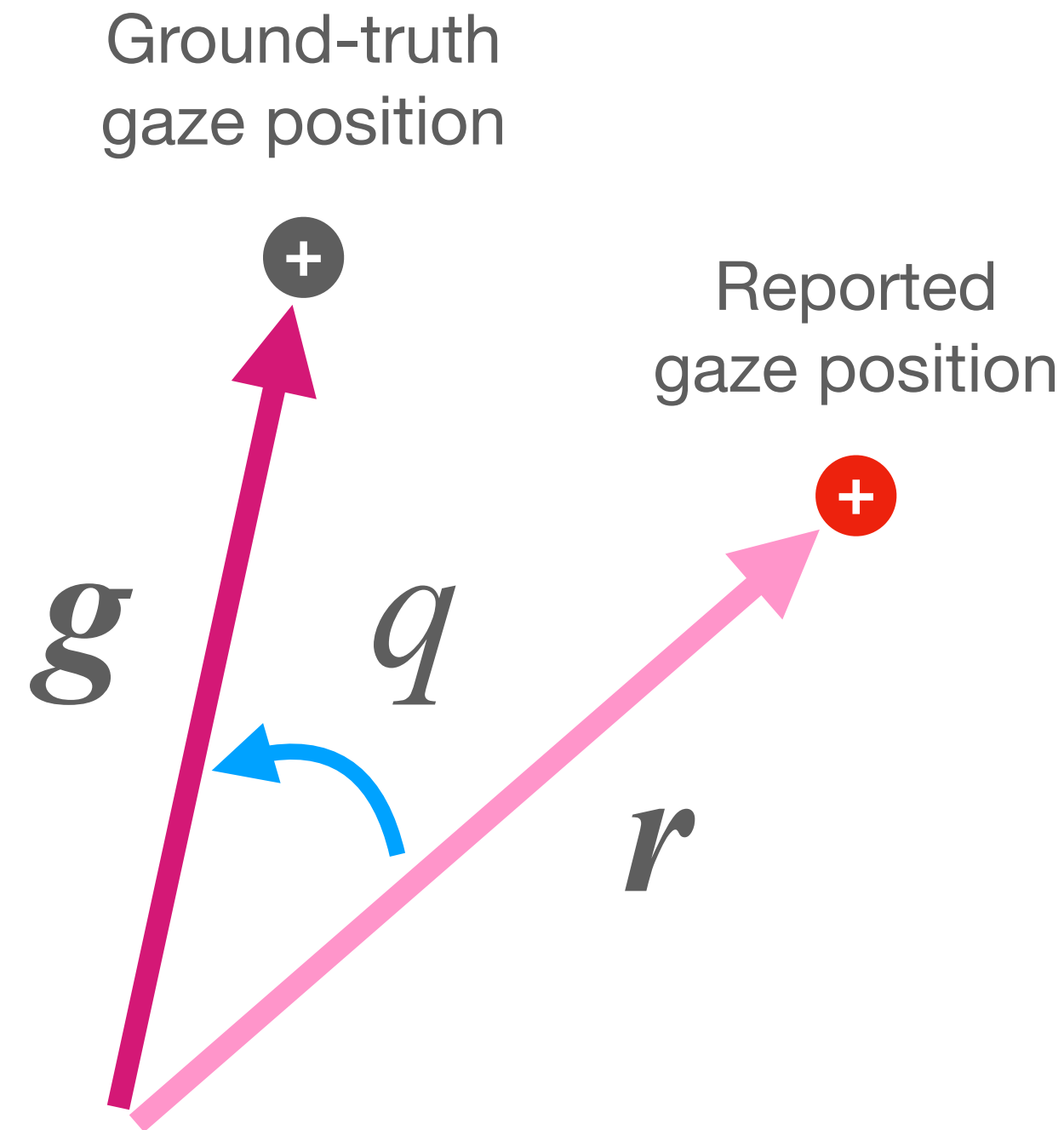
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$$g = q_{r \rightarrow g} r q_{r \rightarrow g}^* \quad \text{— Angular error correction}$$



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Uncertainty representation quaternion

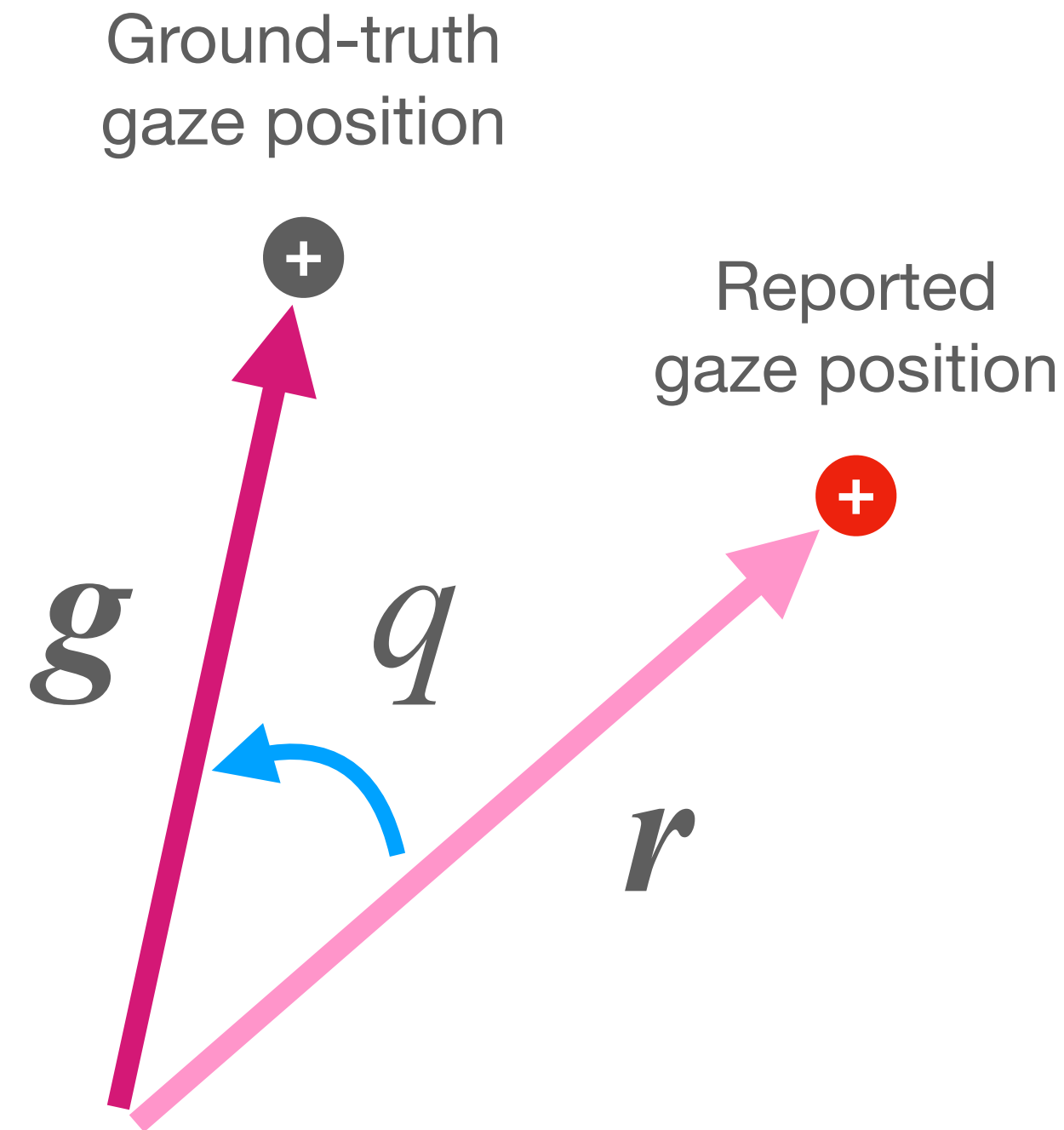
Reported gaze direction

Ground-truth gaze direction

$$q_{r \rightarrow g} = \frac{q}{|q|} \quad \text{— Quaternion normalization}$$

$$g = q_{r \rightarrow g} r q_{r \rightarrow g}^* \quad \text{— Angular error correction}$$

$$CF(r) = \text{Re}(q_{r \rightarrow g}) \quad \text{— Certainty factor}$$



$$q = \begin{cases} \{r \cdot g + 1, r \times g\}, & r \cdot g \neq -1 \\ \{0, u\}, & u \cdot r = 0, \quad r \cdot g = -1 \end{cases}$$

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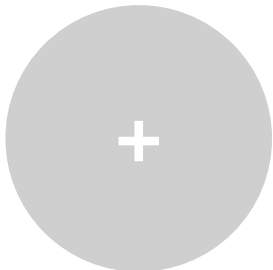
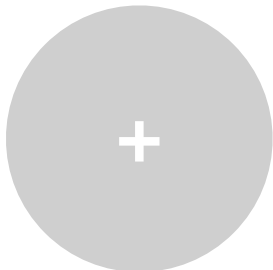
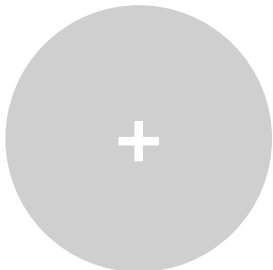
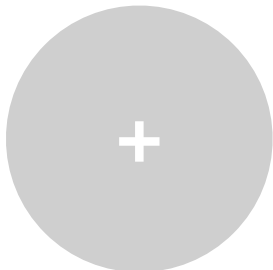
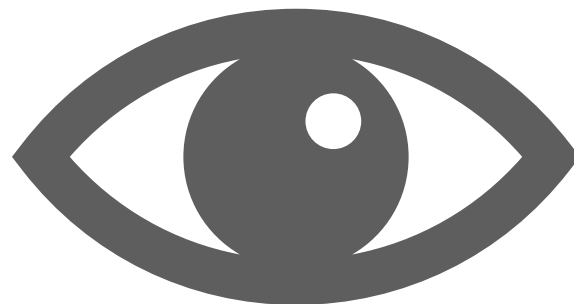
$$q_{r \rightarrow g} = \frac{q}{|q|} \quad \text{— Quaternion normalization}$$

$$g = q_{r \rightarrow g} r q_{r \rightarrow g}^* \quad \text{— Angular error correction}$$

$$\text{CF}(r) = \text{Re}(q_{r \rightarrow g}) \quad \text{— Certainty factor}$$

$$\psi_r = 2 \arccos(\text{CF}(r)) \quad \text{— Angular error assessment}$$

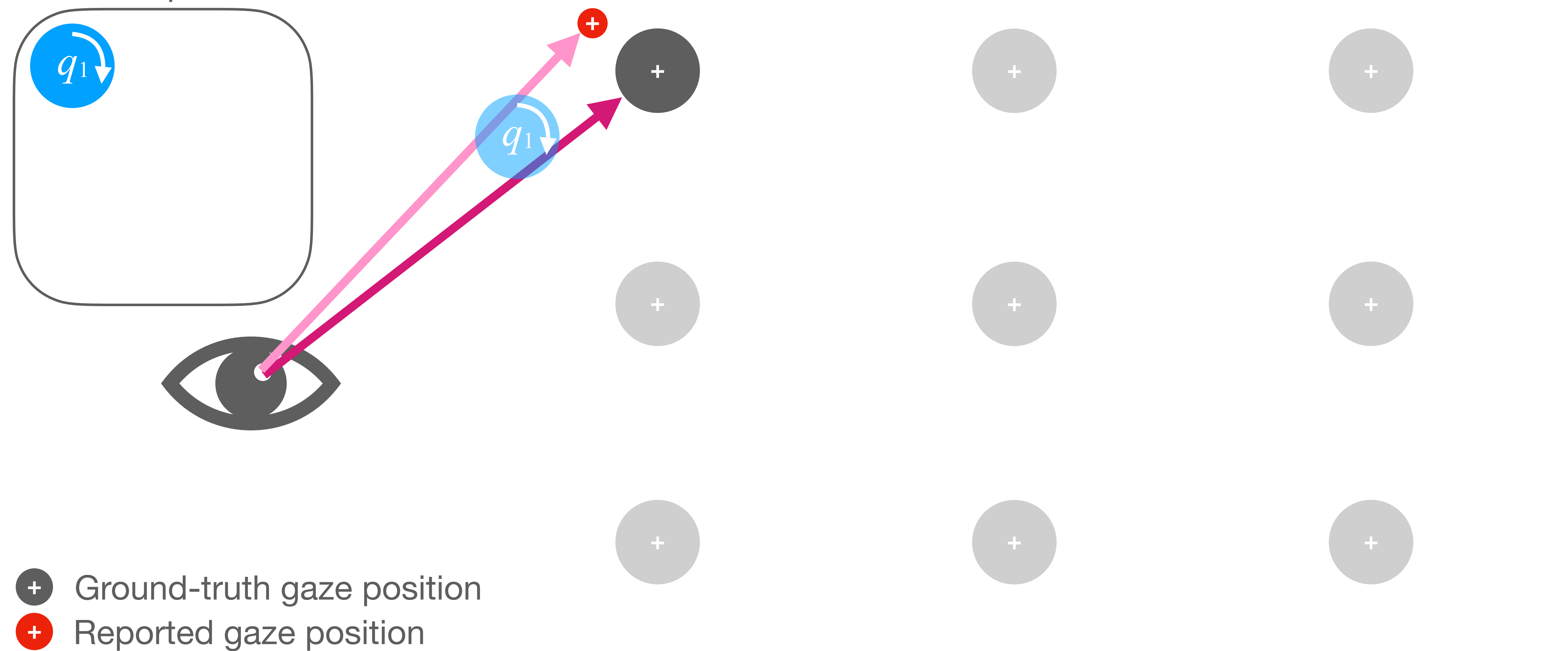
Reference quaternions



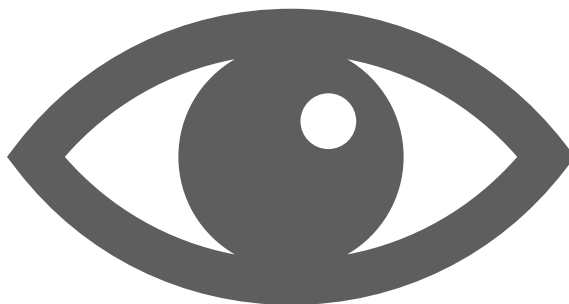
 Ground-truth gaze position

 Reported gaze position

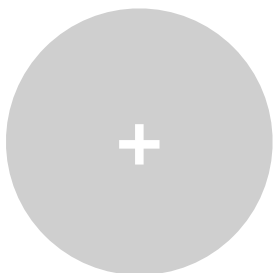
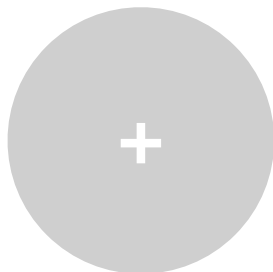
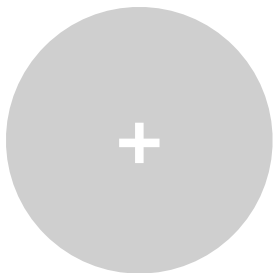
Reference quaternions



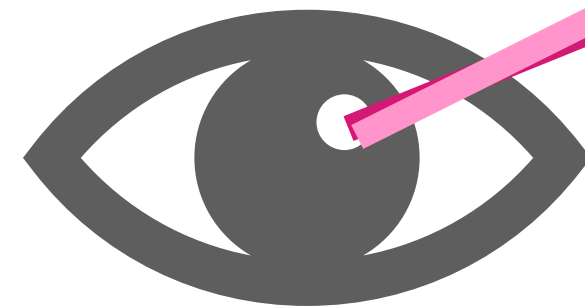
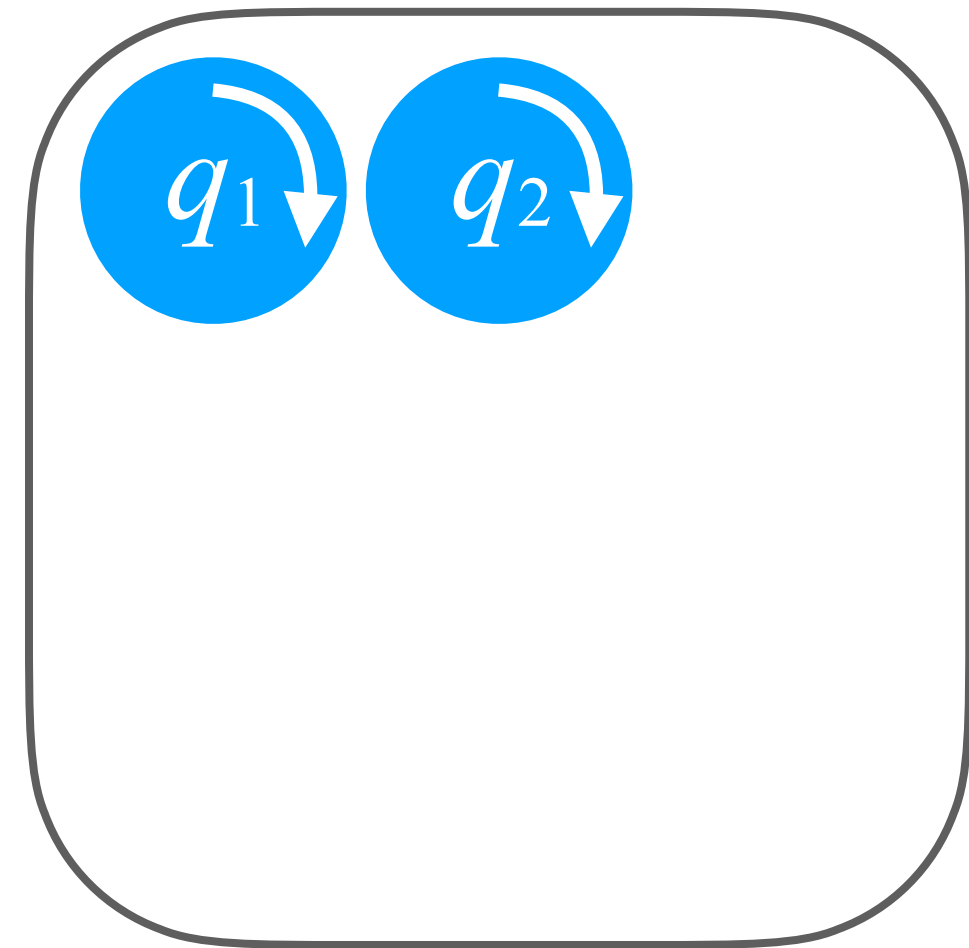
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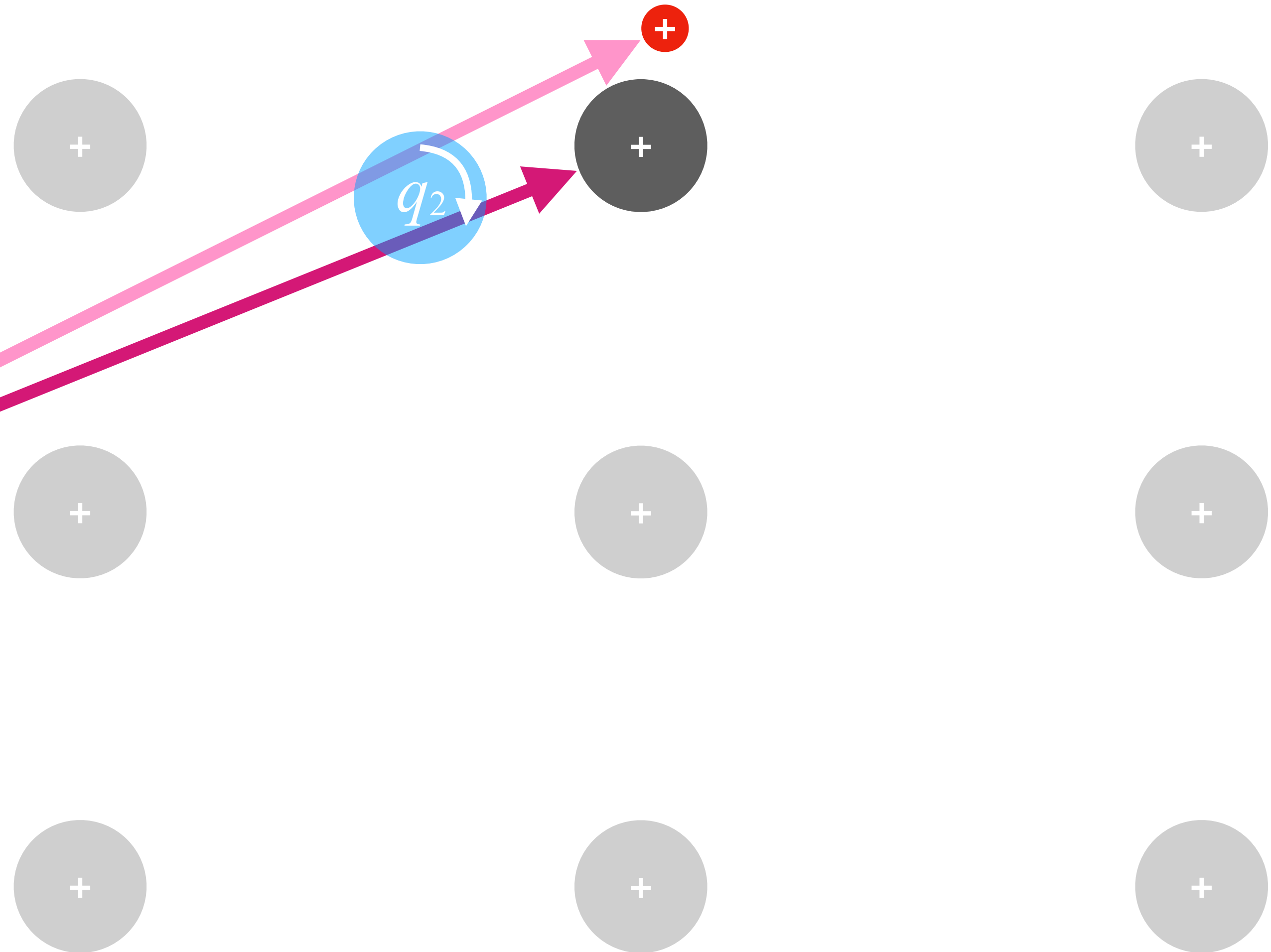
-  Ground-truth gaze position
-  Reported gaze position



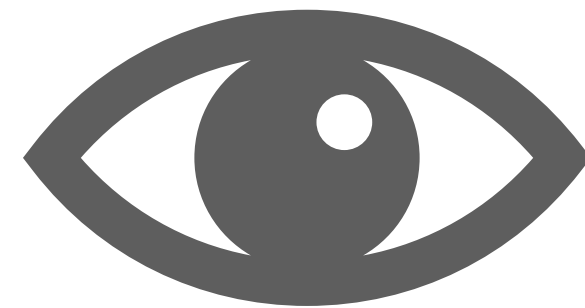
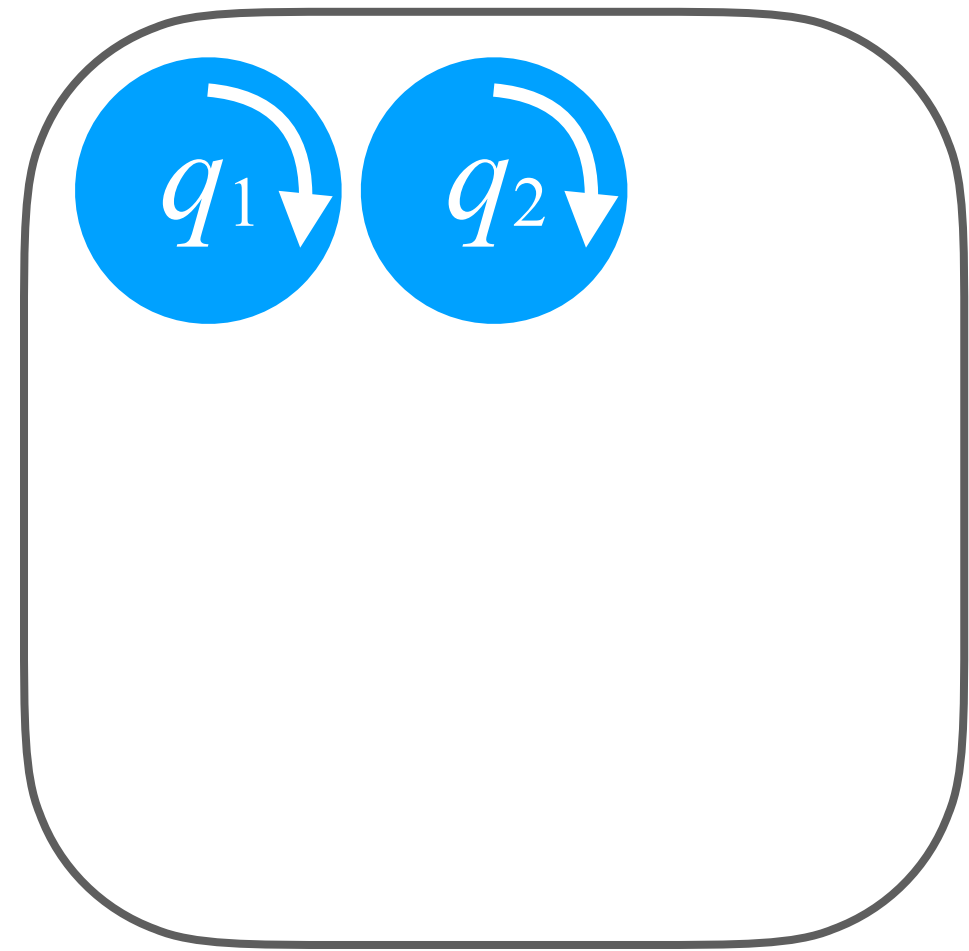
Reference quaternions



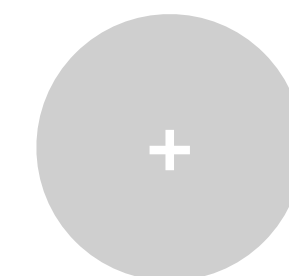
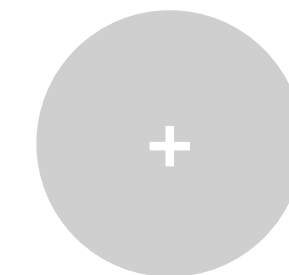
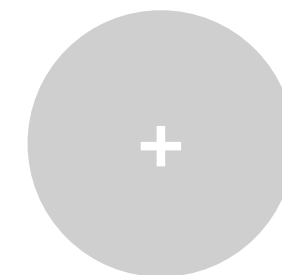
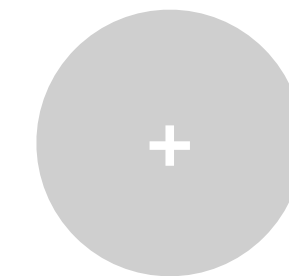
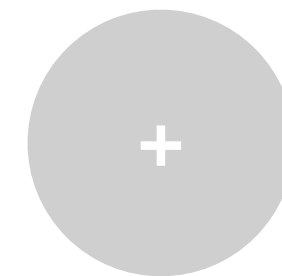
-  Ground-truth gaze position
-  Reported gaze position



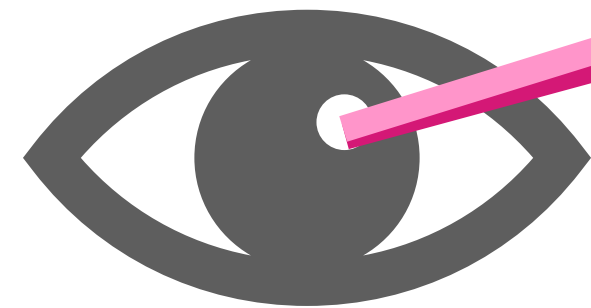
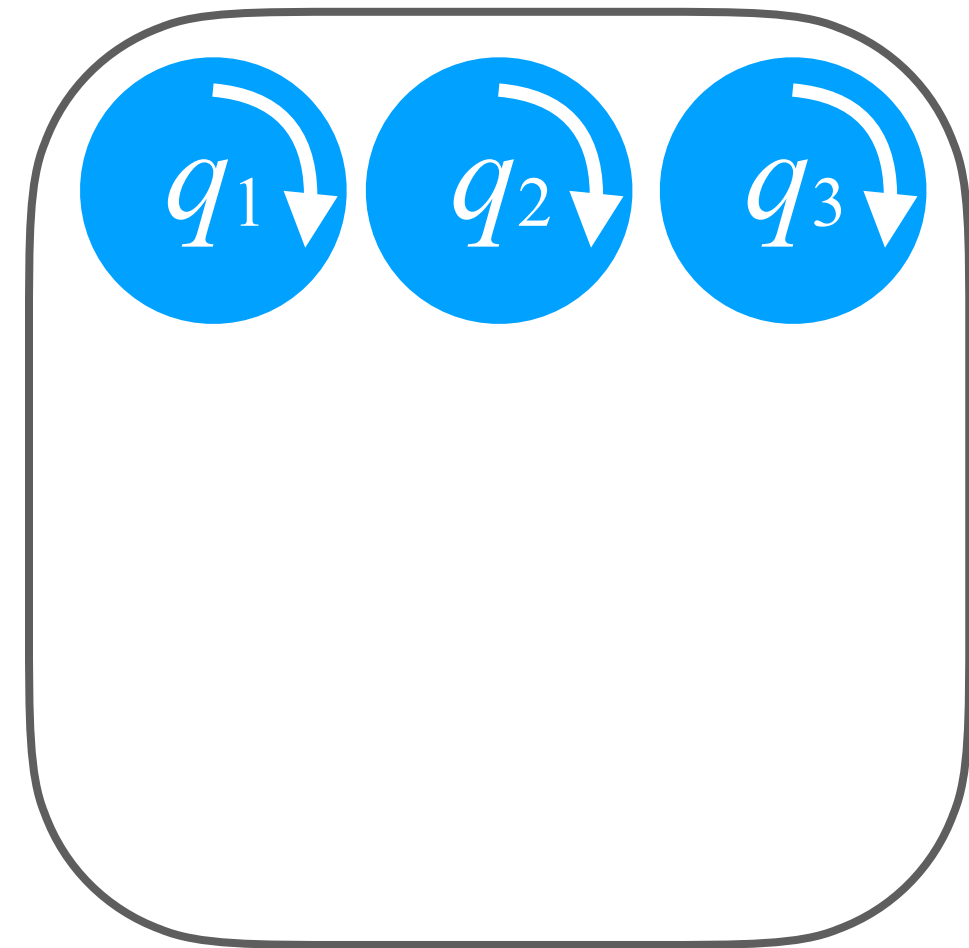
Reference quaternions



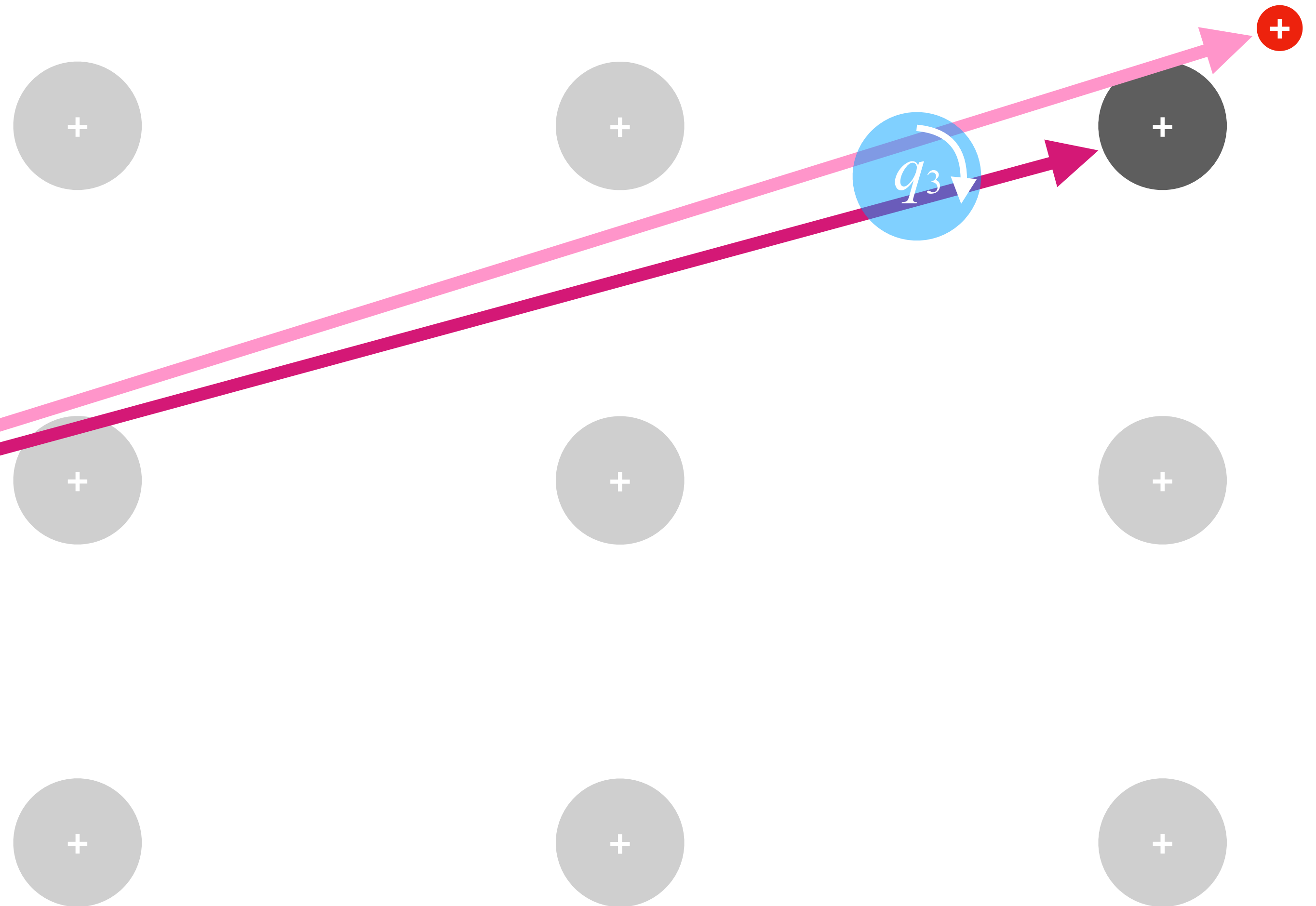
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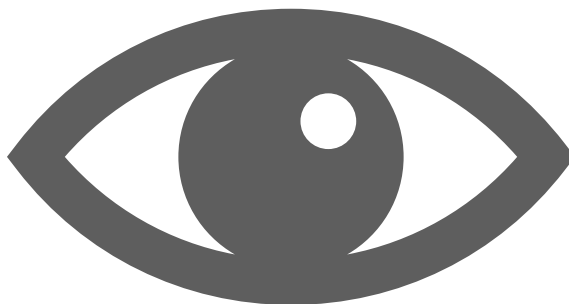
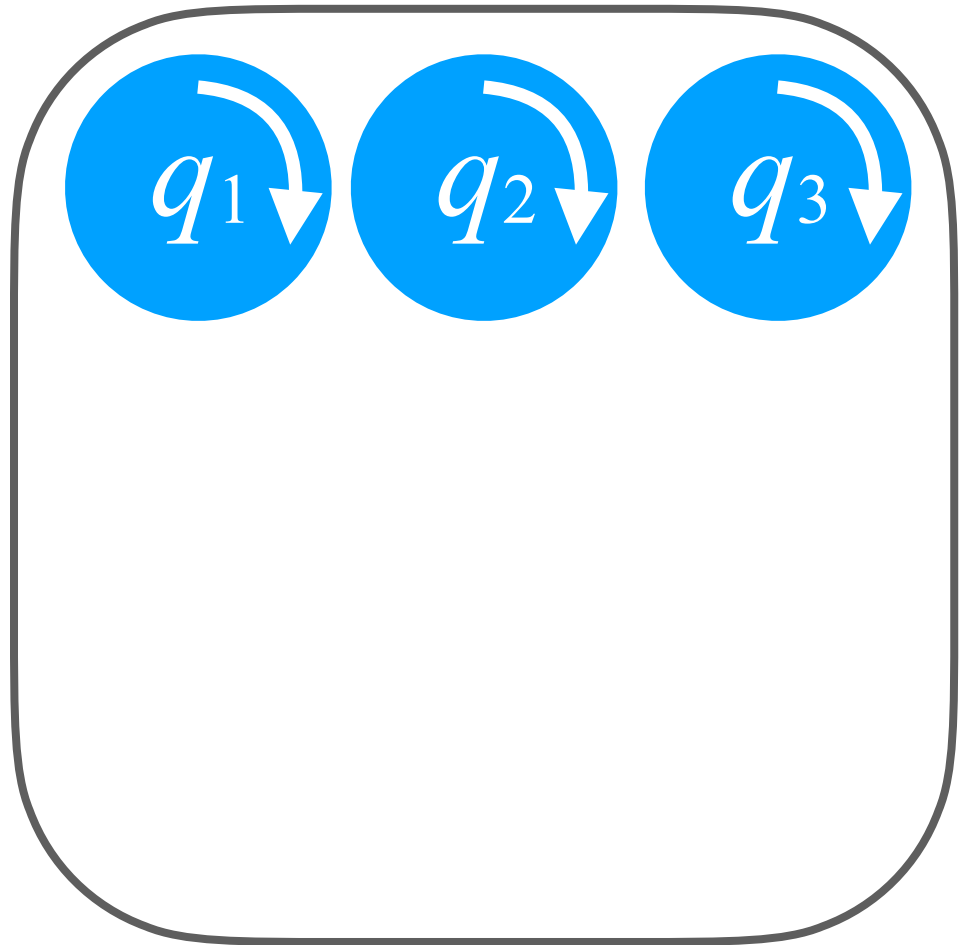
Reference quaternions



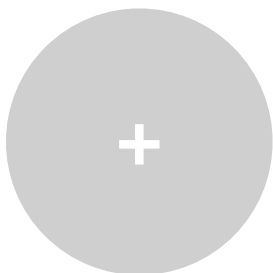
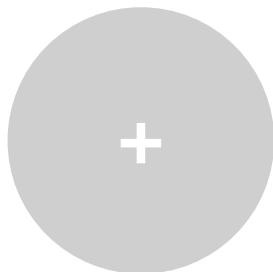
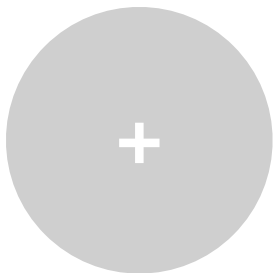
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-  Reported gaze position



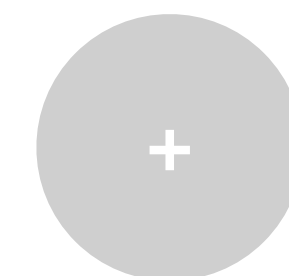
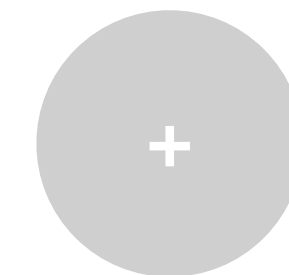
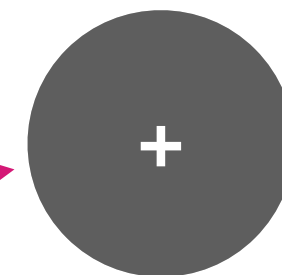
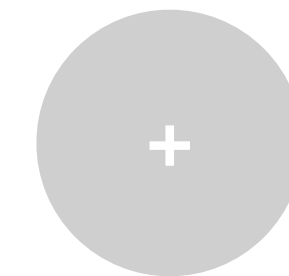
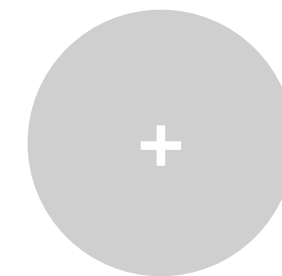
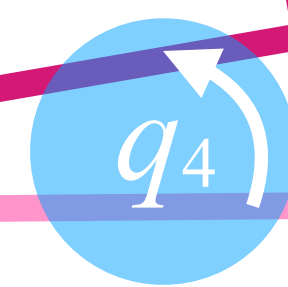
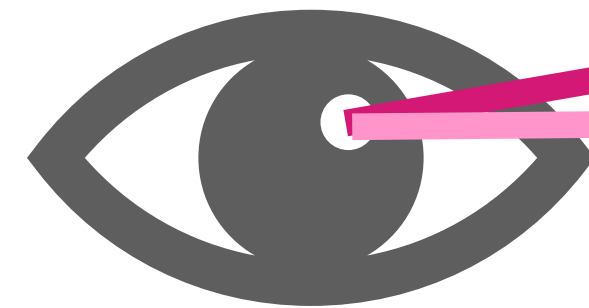
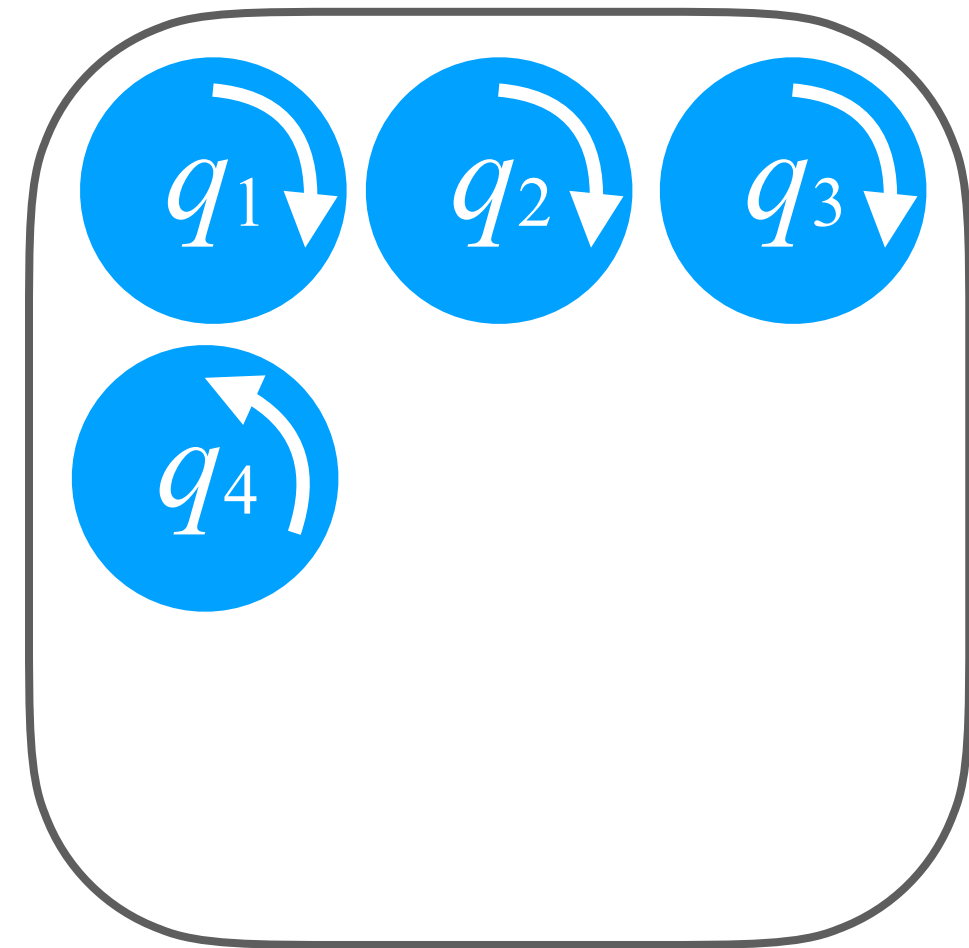
Reference quaternions



-  Ground-truth gaze position
-  Reported gaze position



Reference quaternions

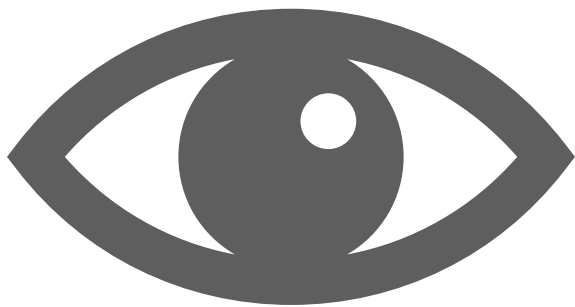
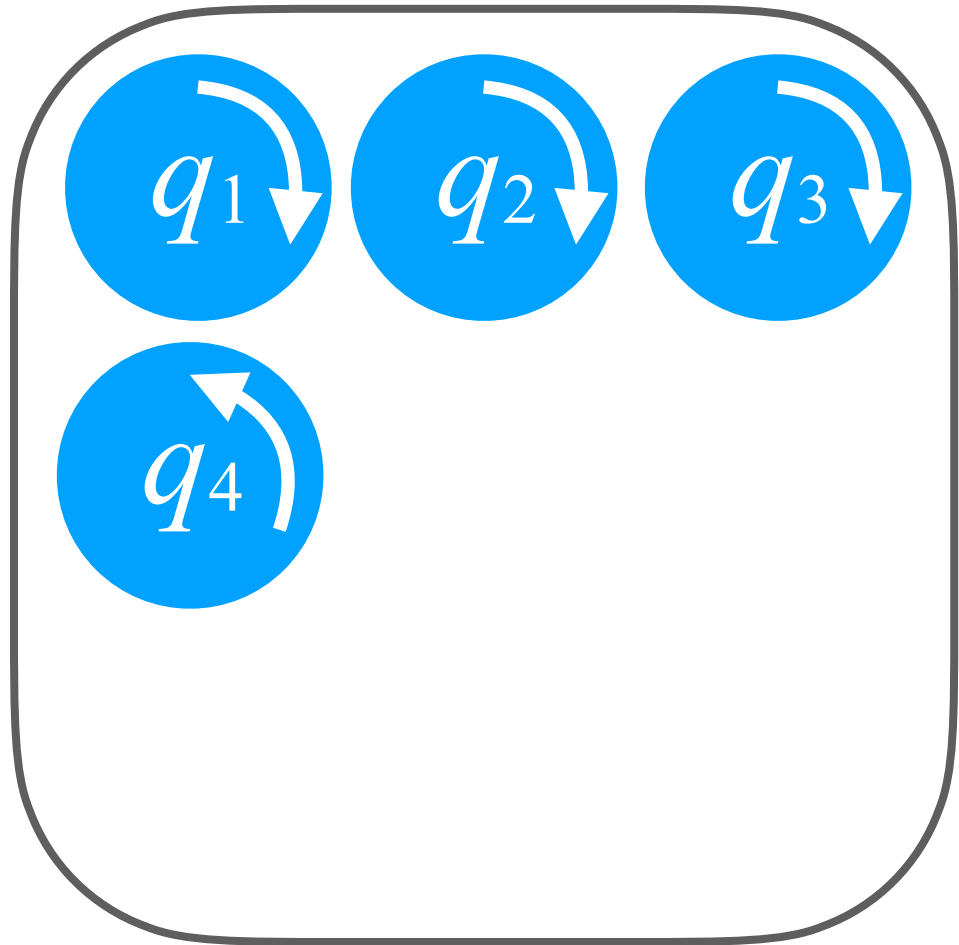


Ground-truth gaze position

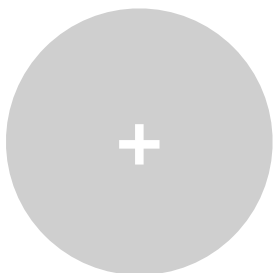
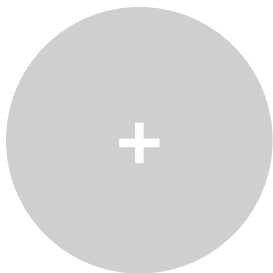


Reported gaze position

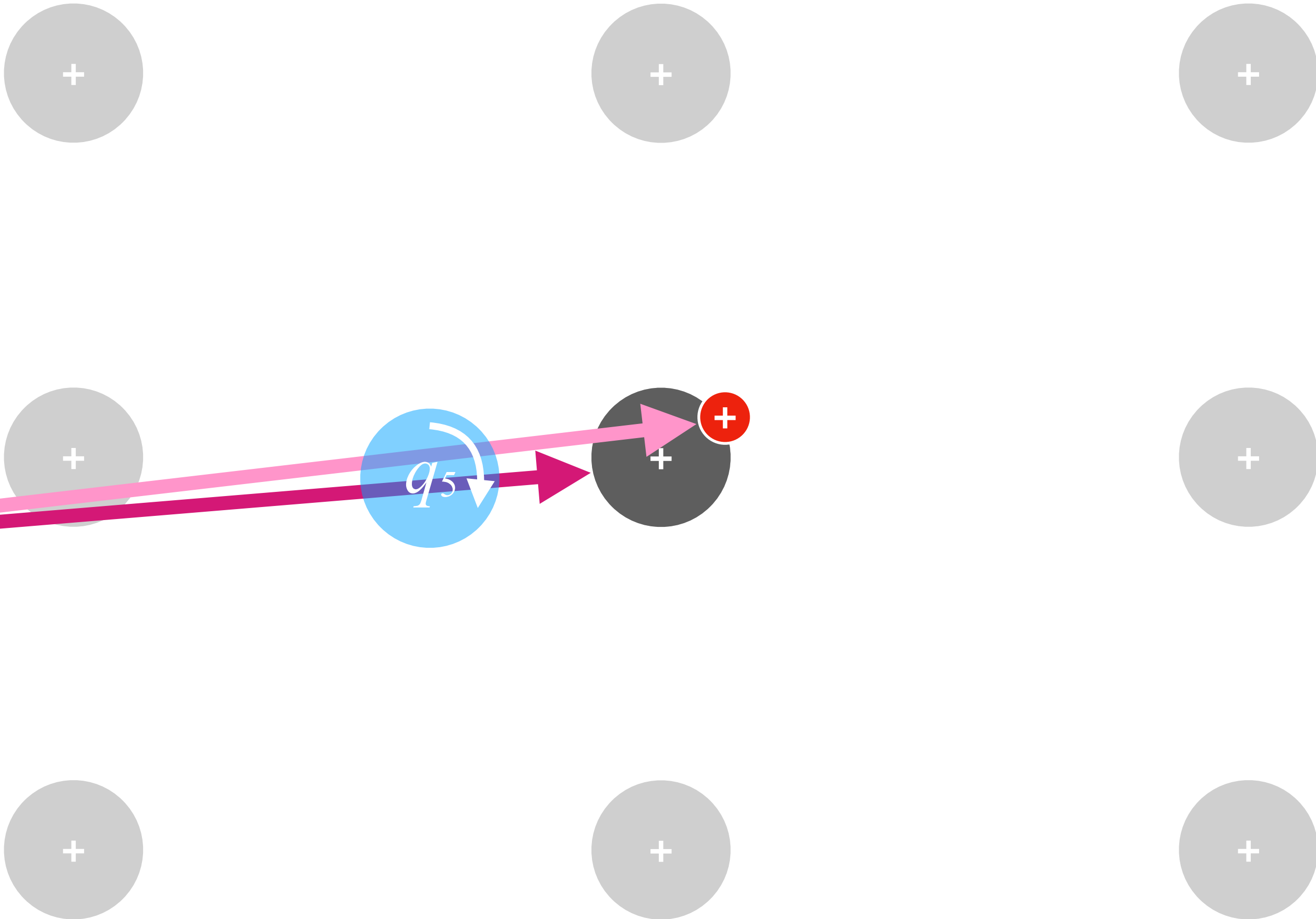
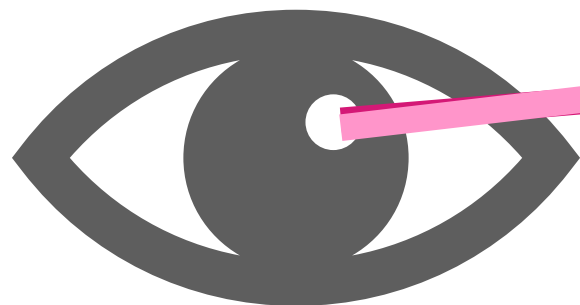
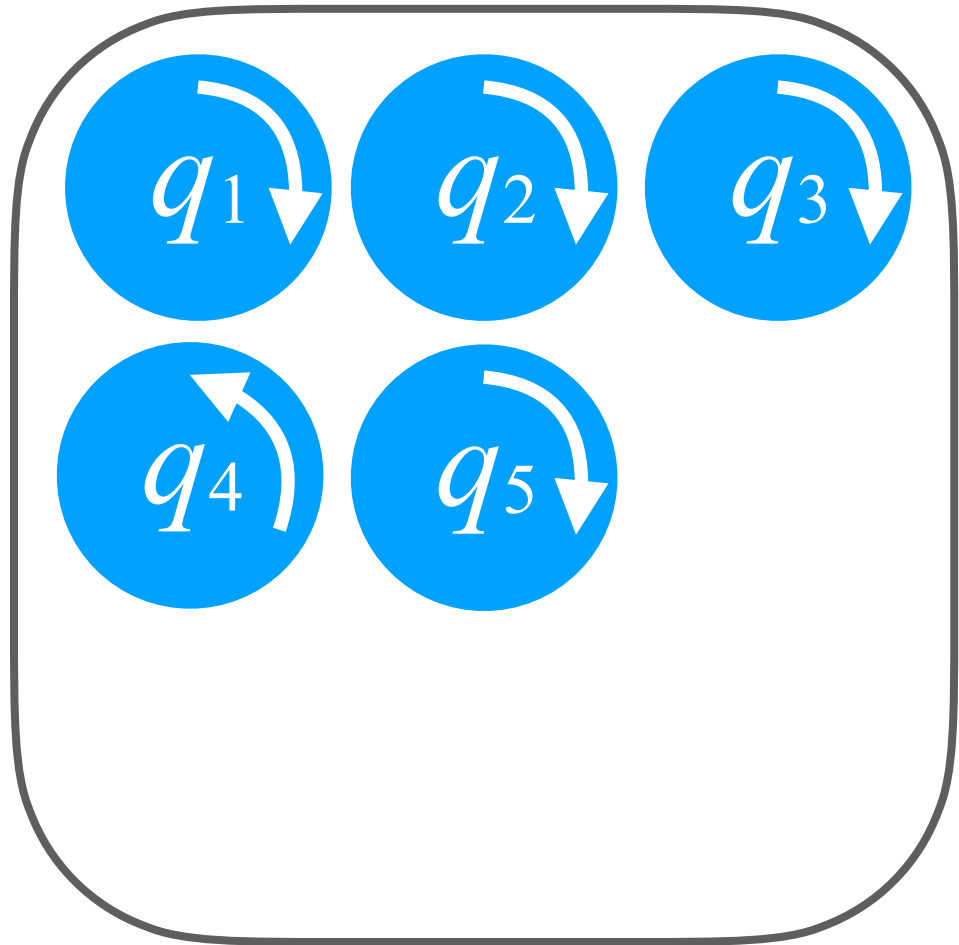
Reference quaternions



-  Ground-truth gaze position
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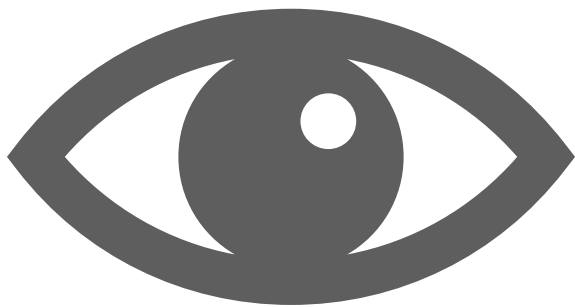
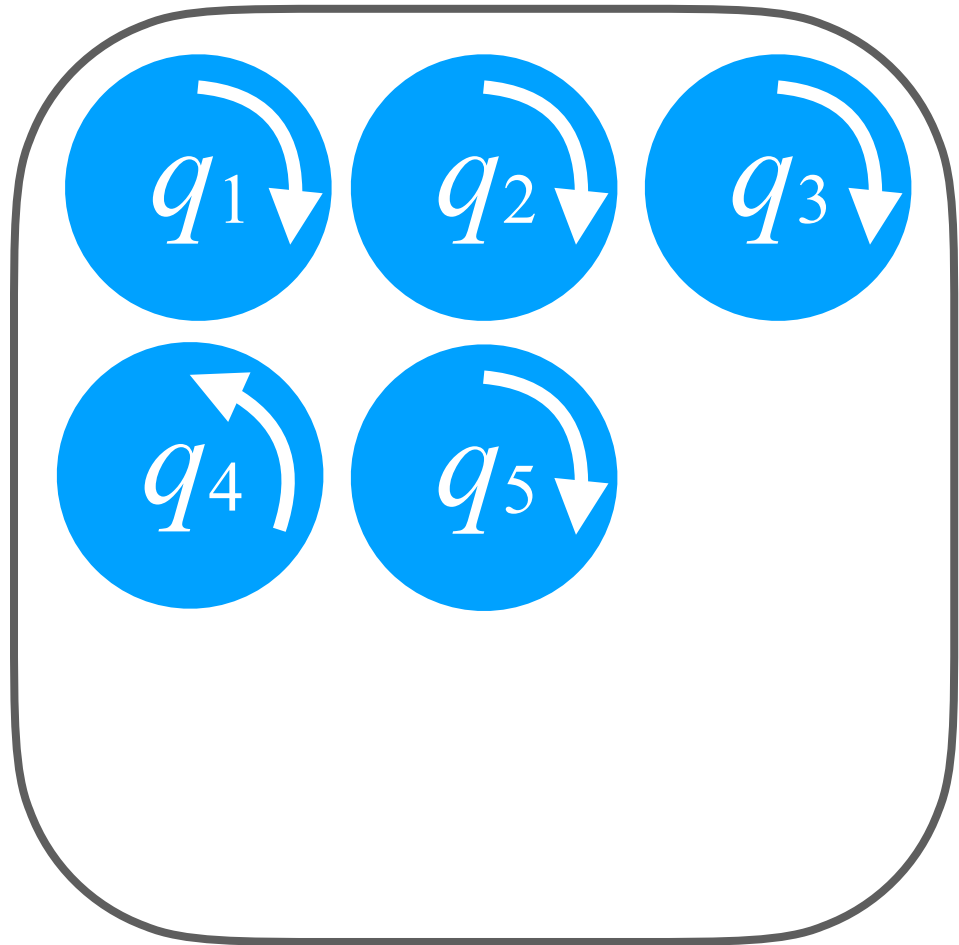


Reference quaternions

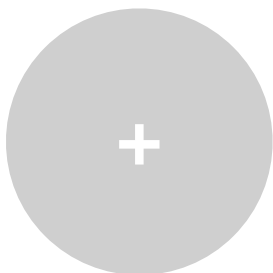
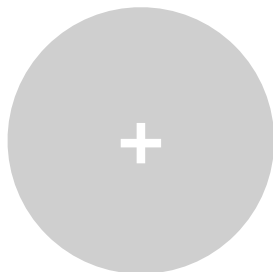
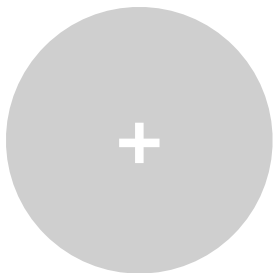


-  Ground-truth gaze position
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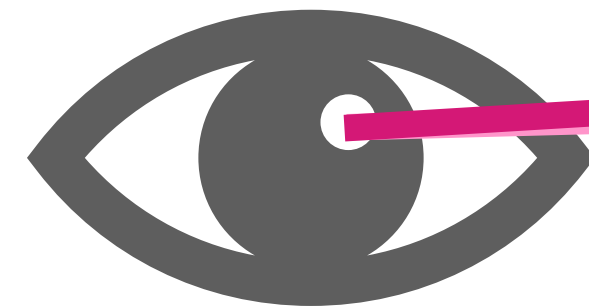
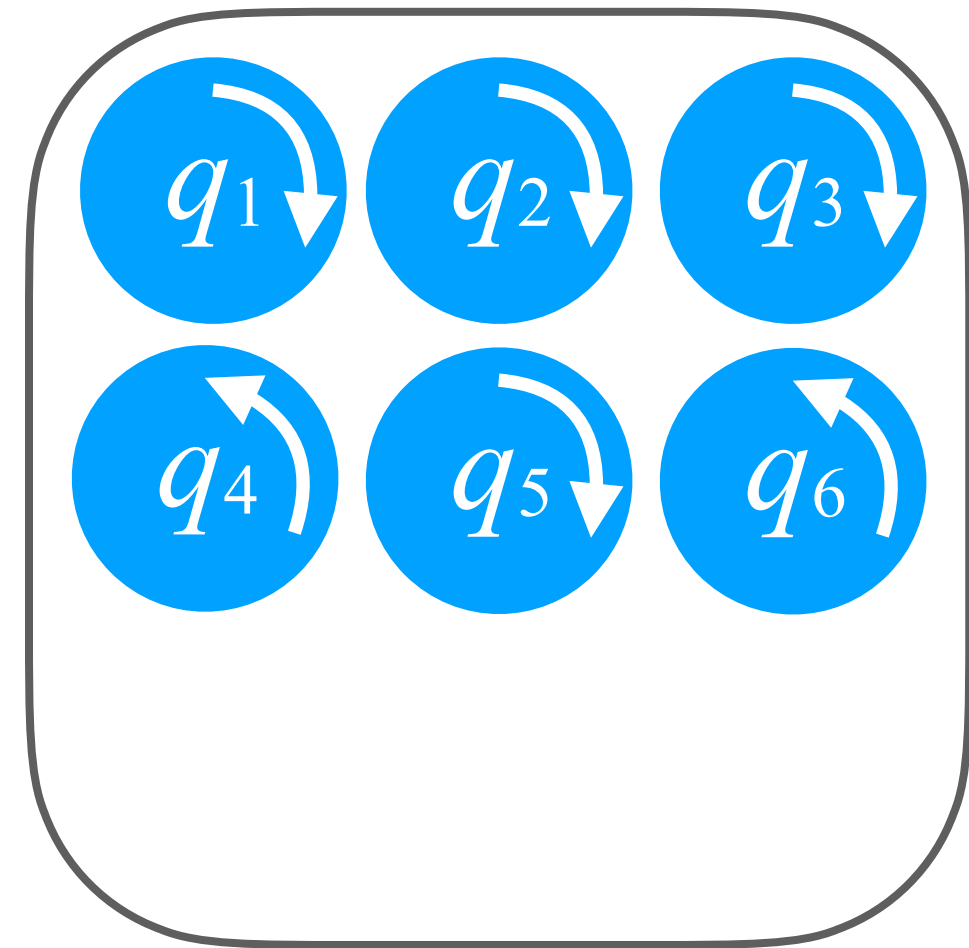
Reference quaternions



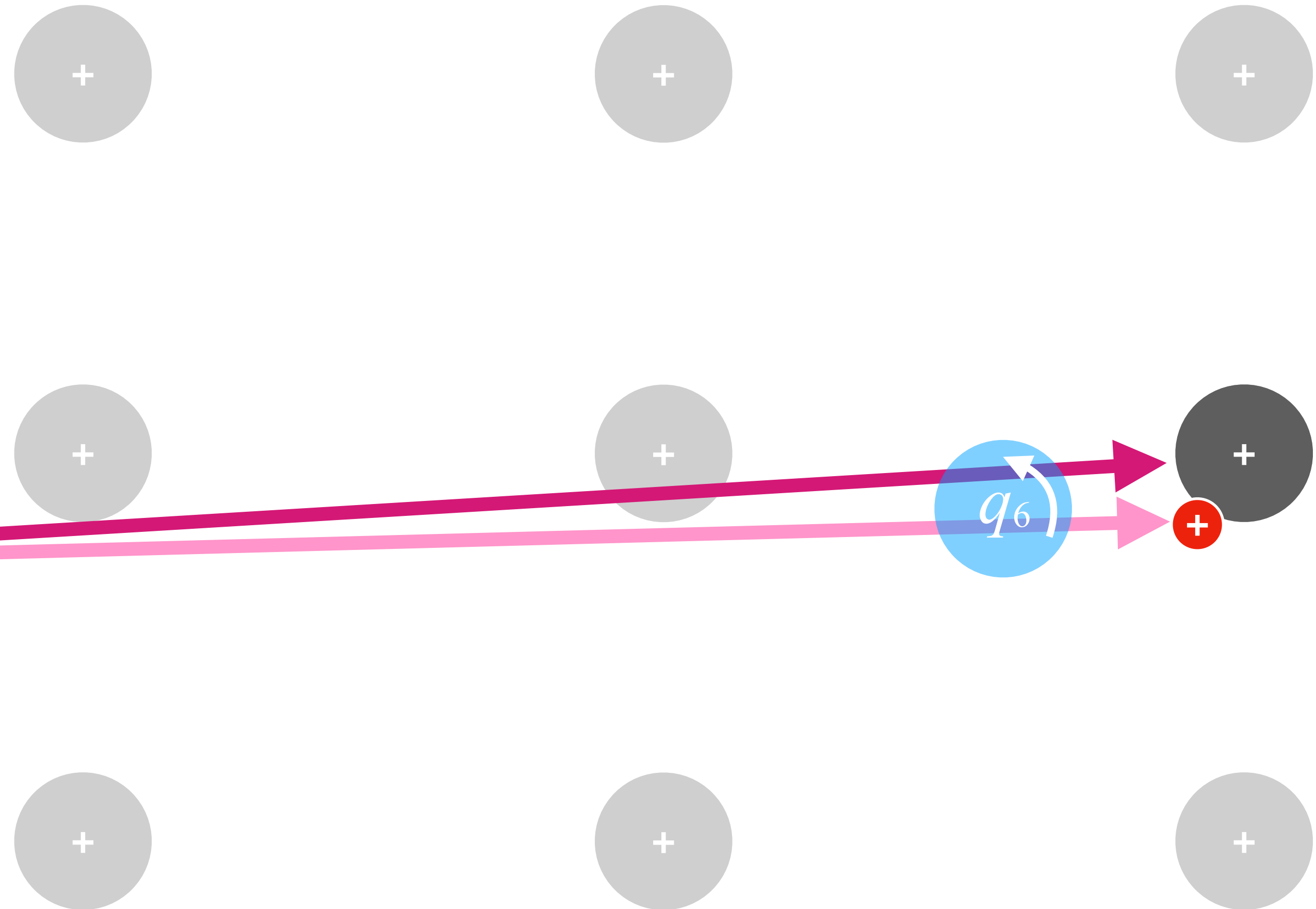
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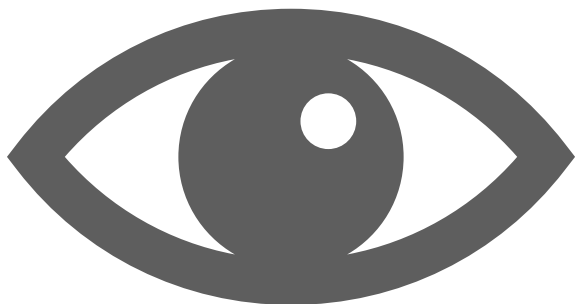
Reference quaternions



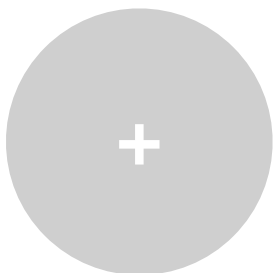
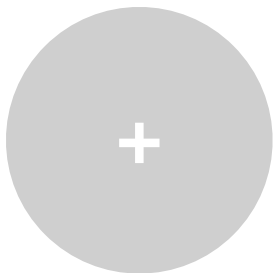
-  Ground-truth gaze position
-  Reported gaze position



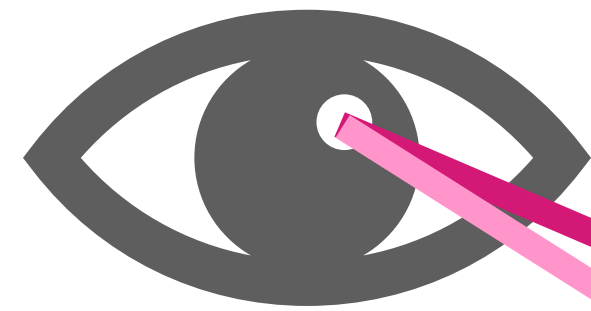
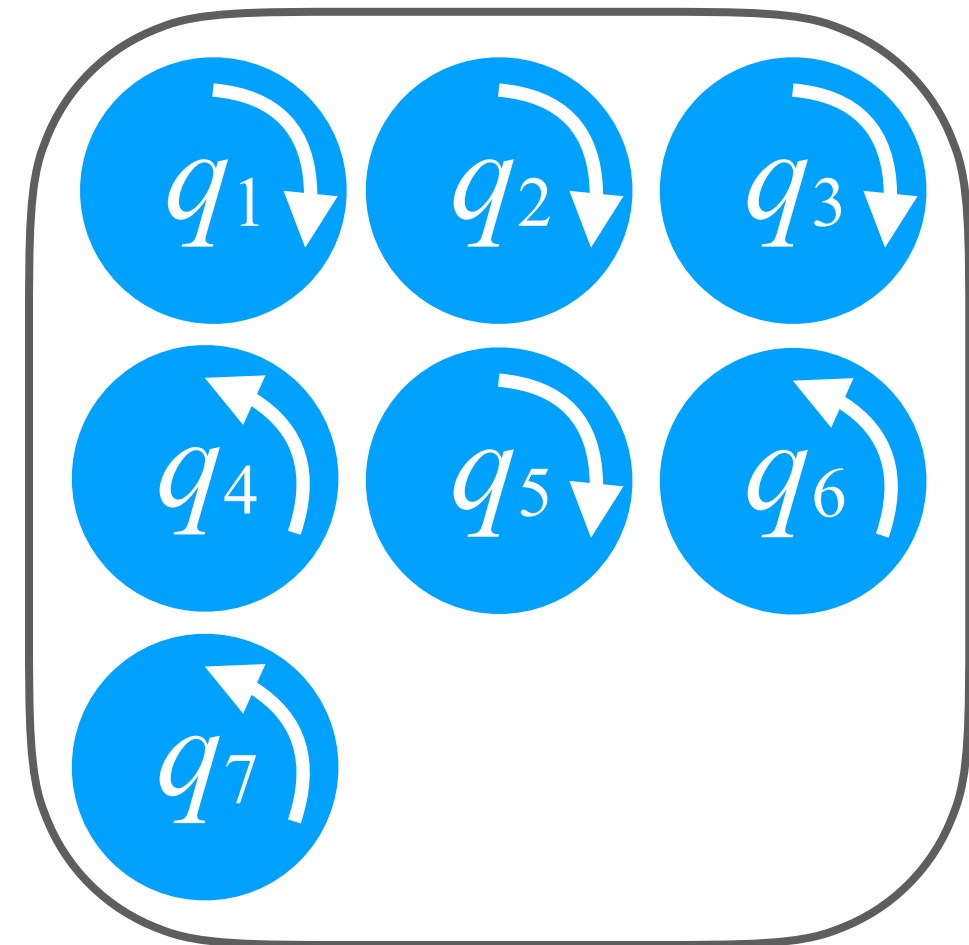
Reference quaternions



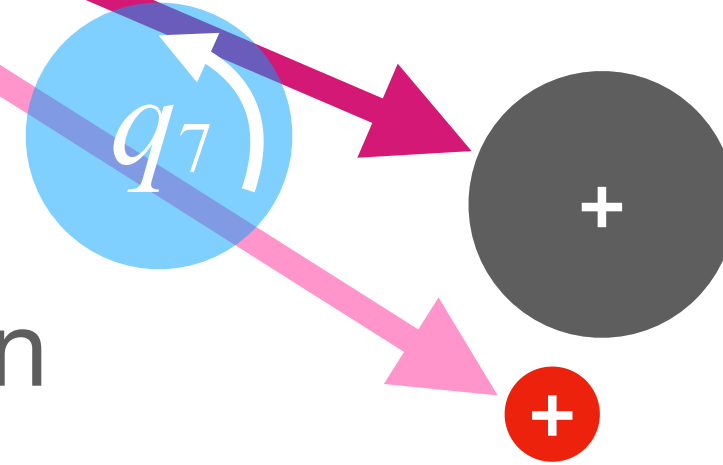
-  Ground-truth gaze position
-  Reported gaze position



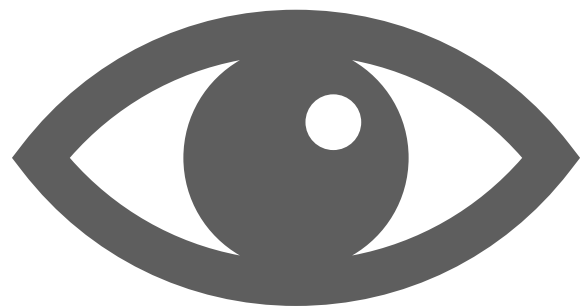
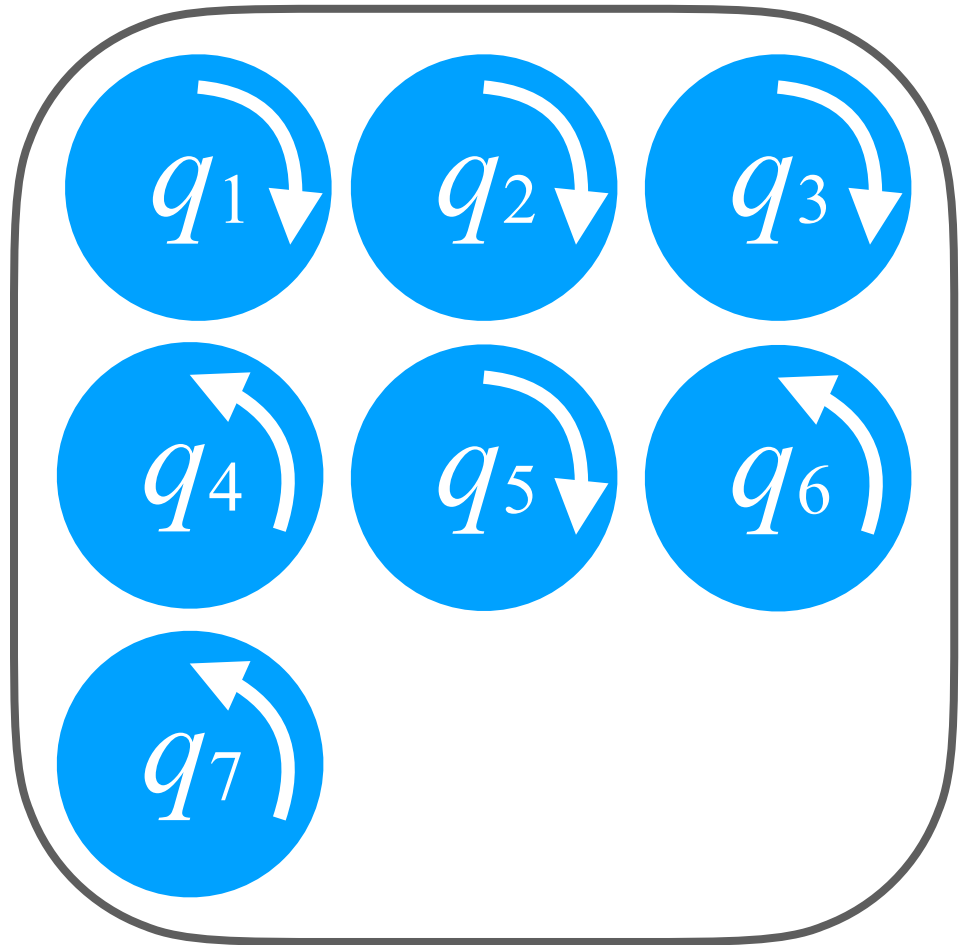
Reference quaternions



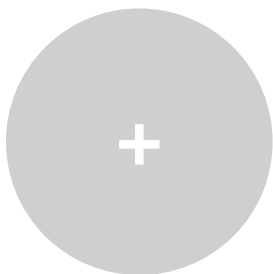
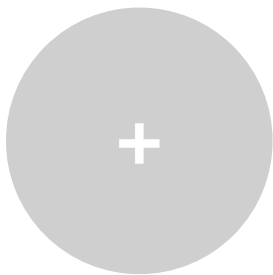
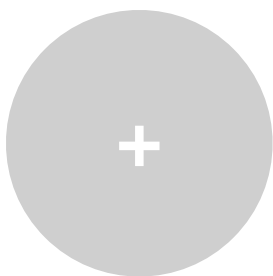
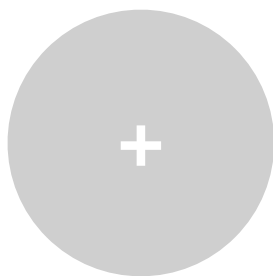
-  Ground-truth gaze position
-  Reported gaze position



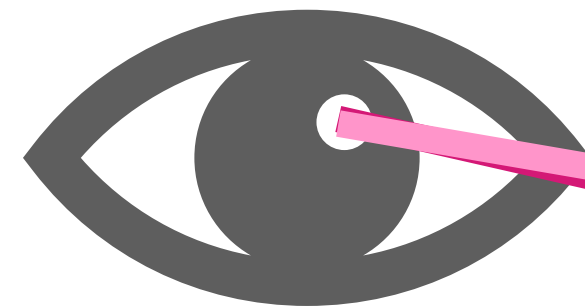
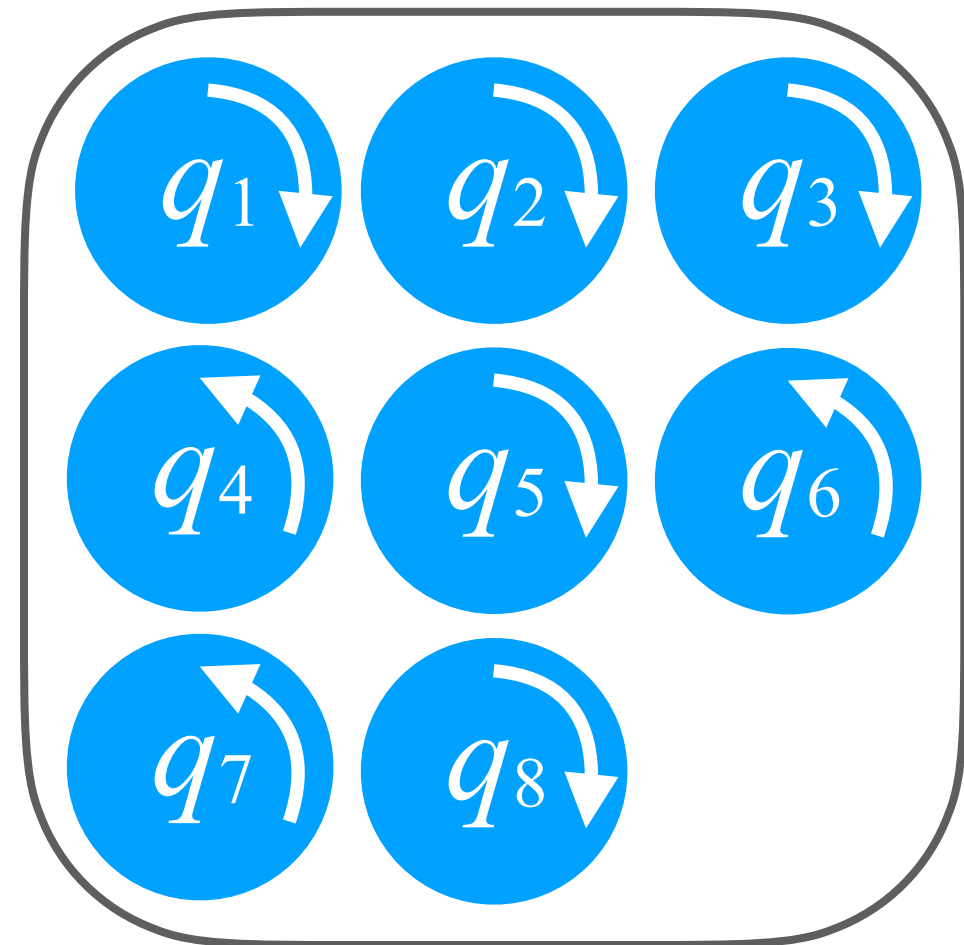
Reference quaternions



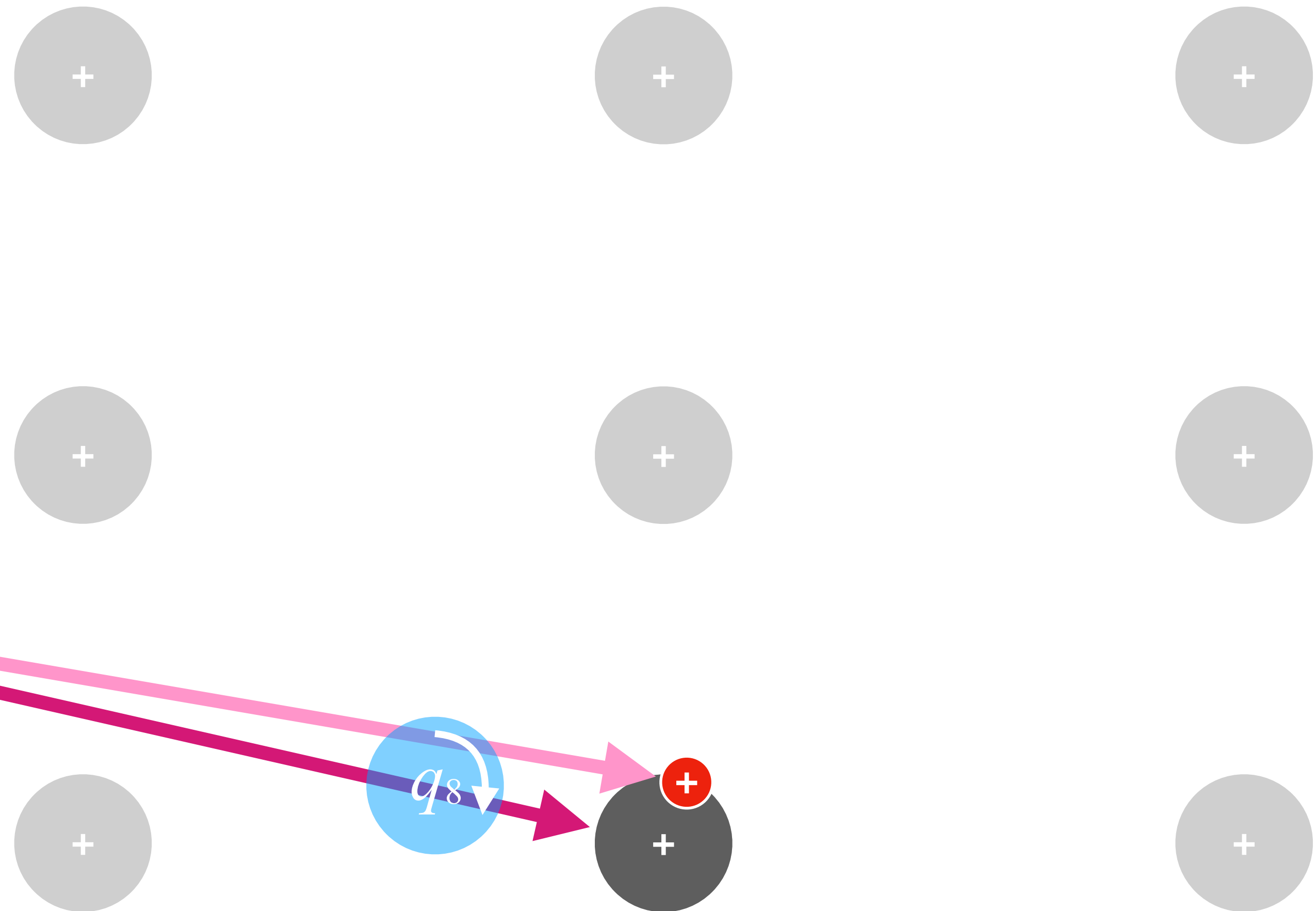
-  Ground-truth gaze position
-  Reported gaze position



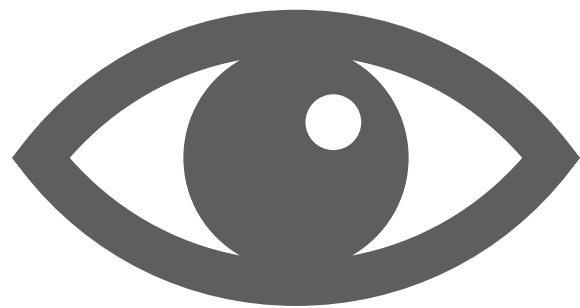
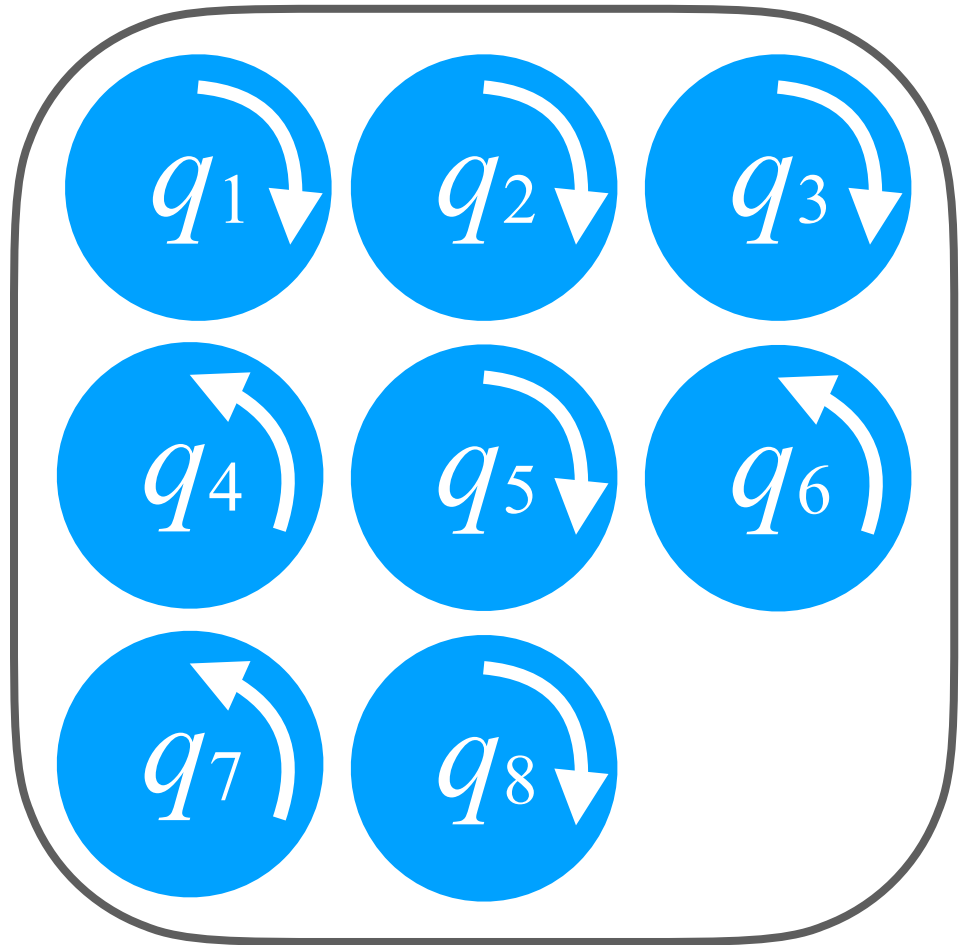
Reference quaternions



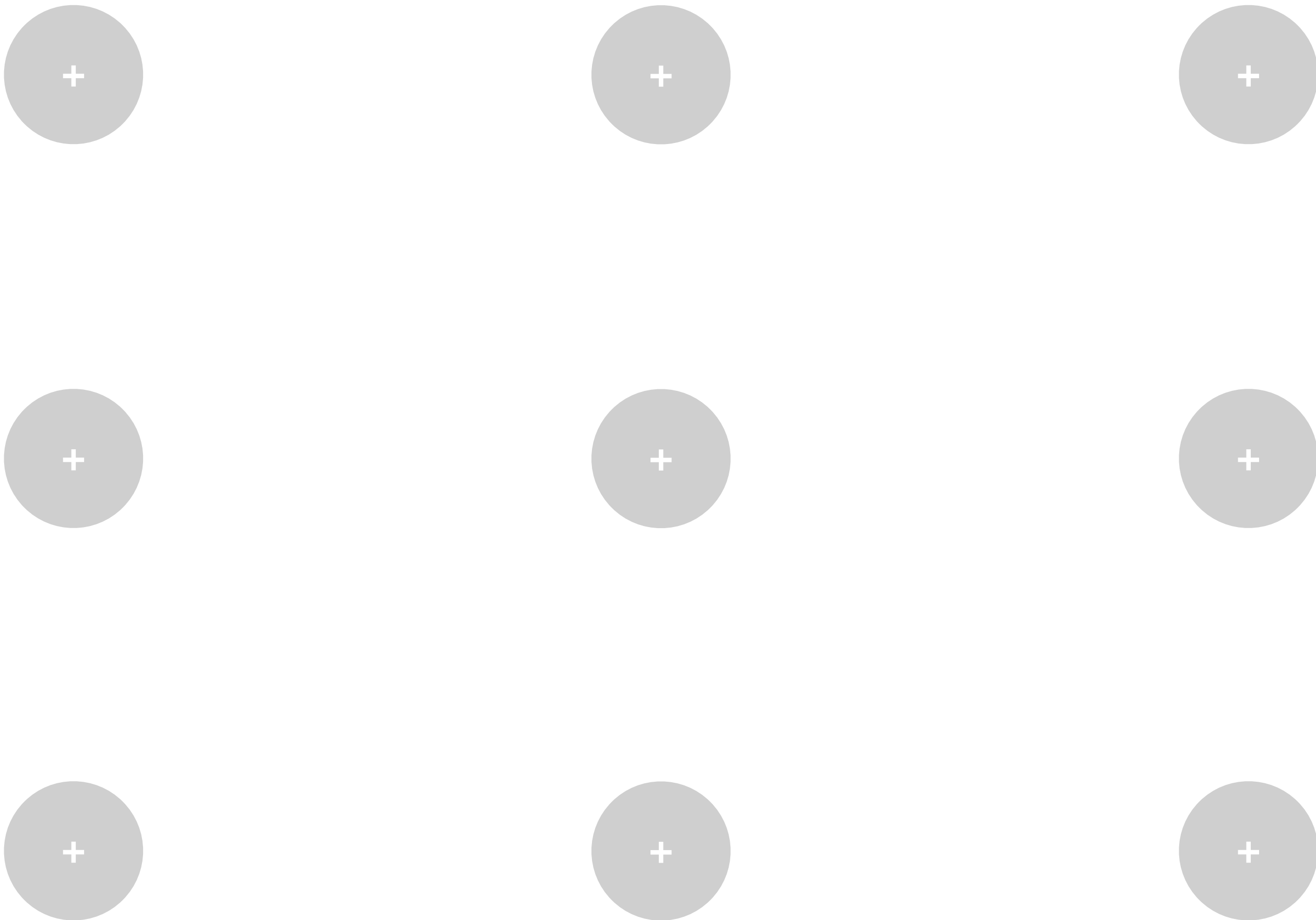
-  Ground-truth gaze position
-  Reported gaze position



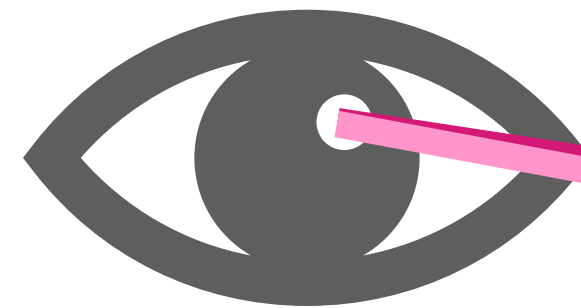
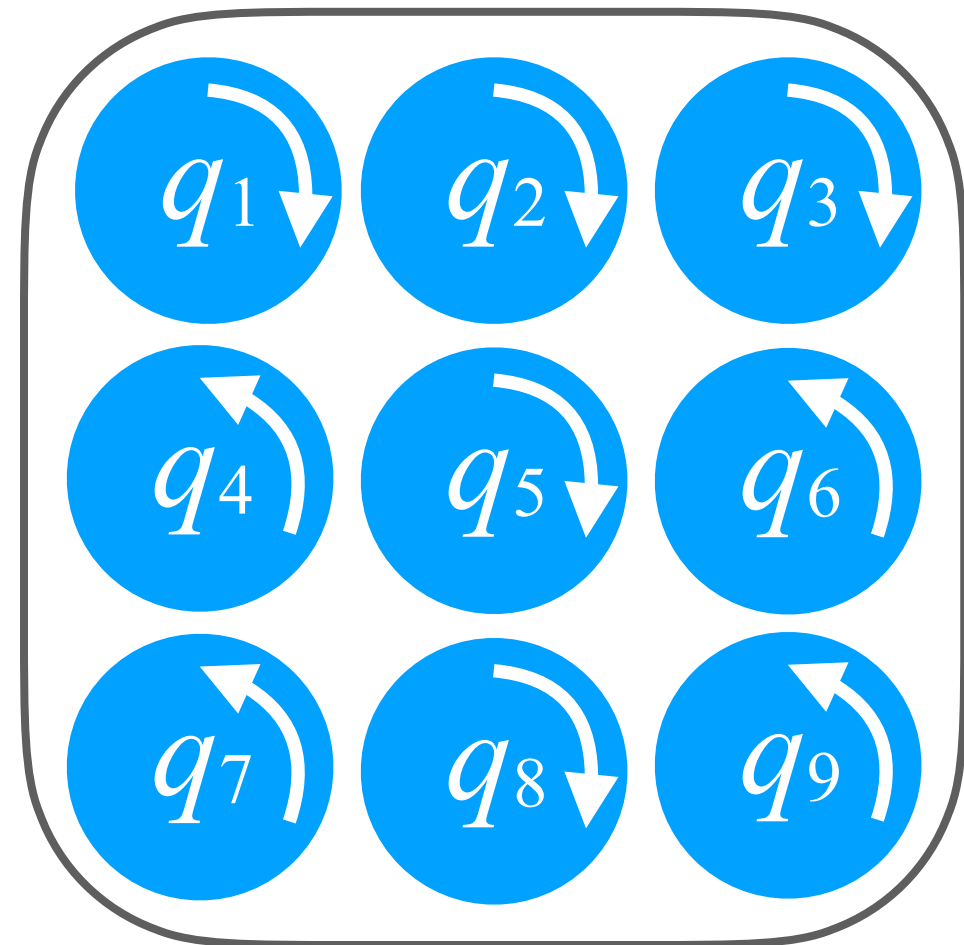
Reference quaternions



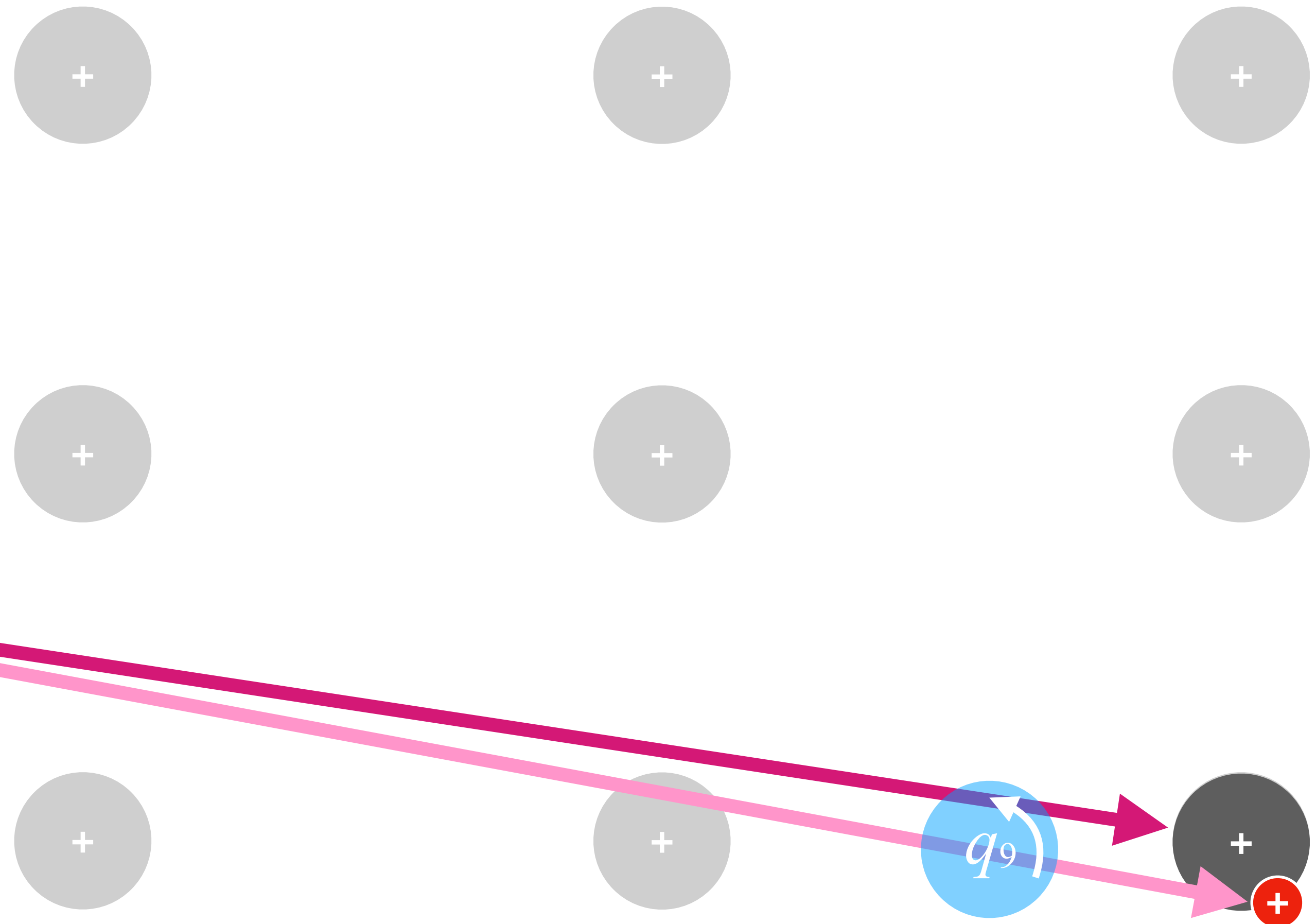
-  Ground-truth gaze position
-  Reported gaze position



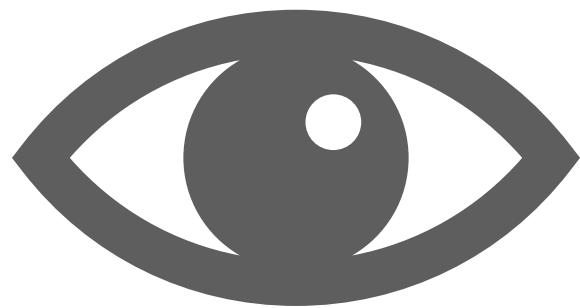
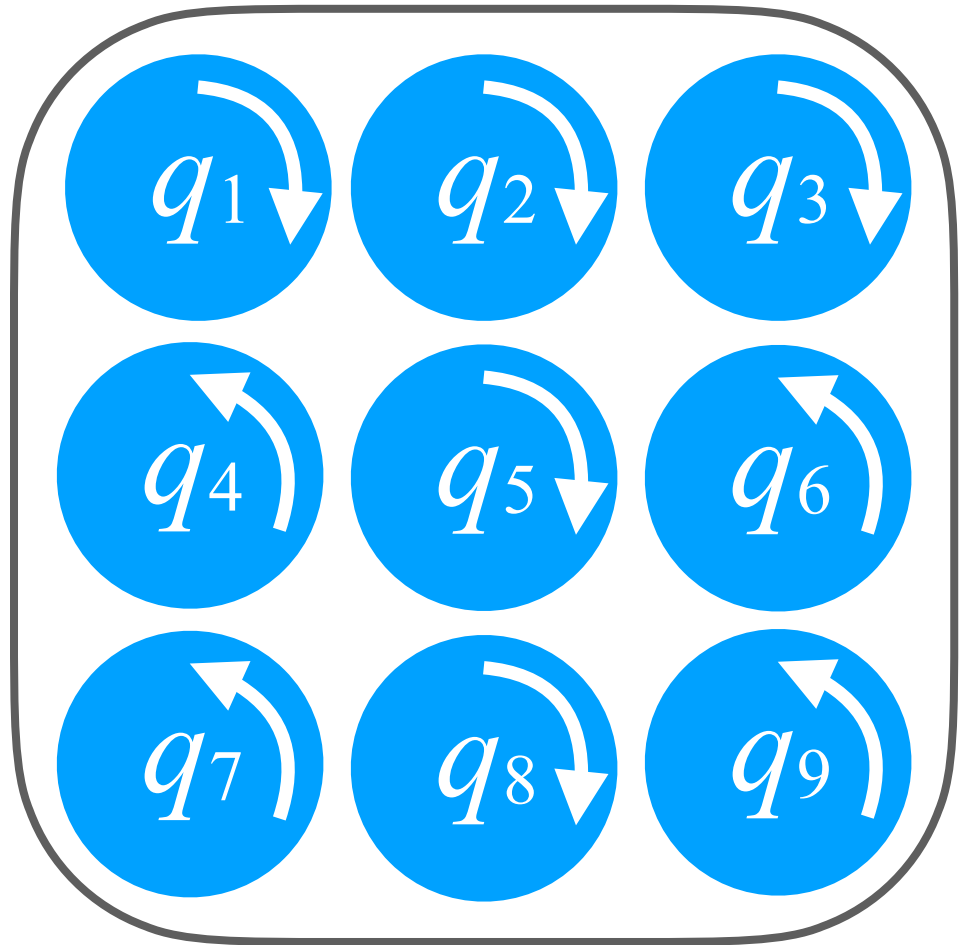
Reference quaternions



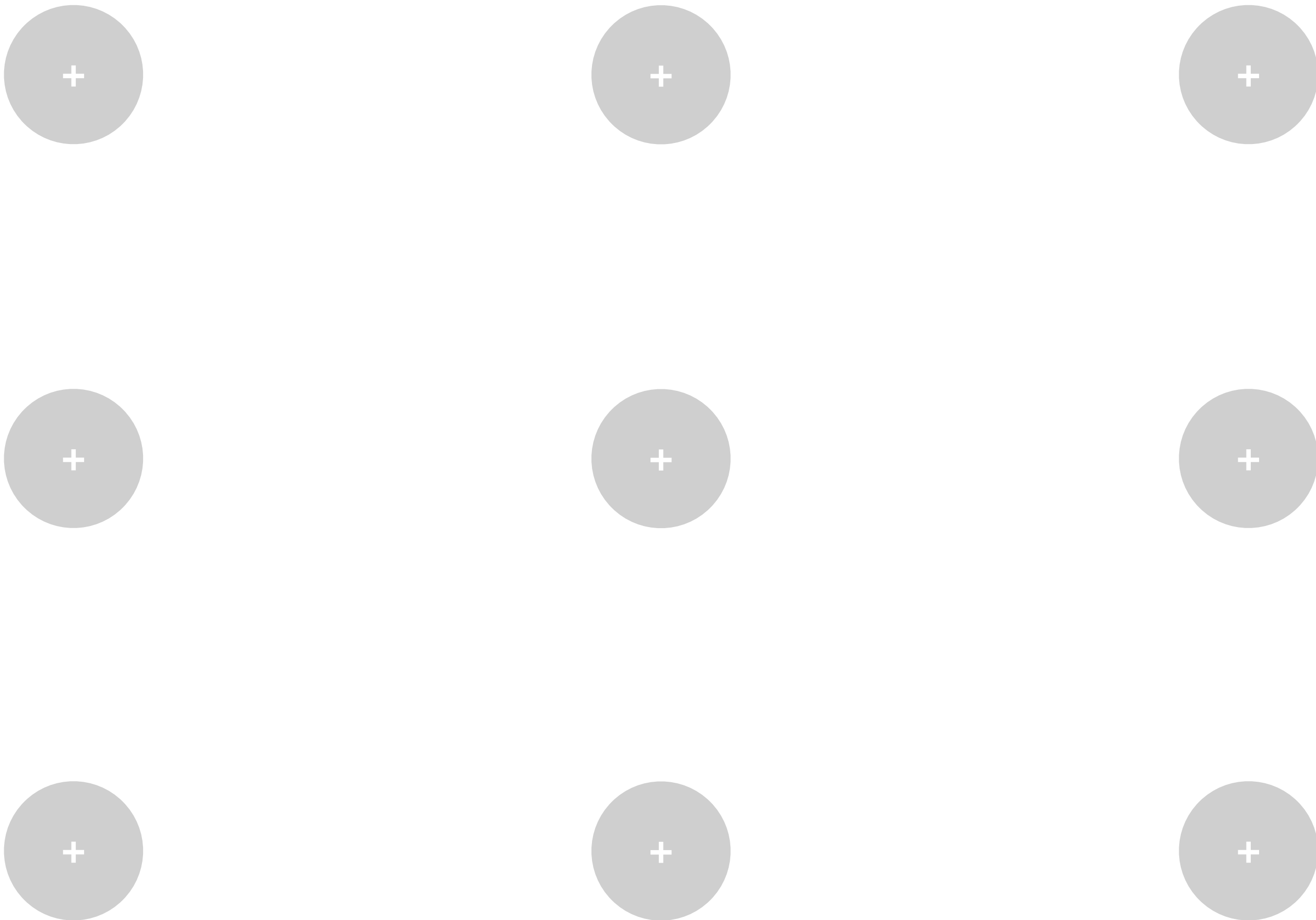
-  Ground-truth gaze position
-  Reported gaze position



Reference quaternions

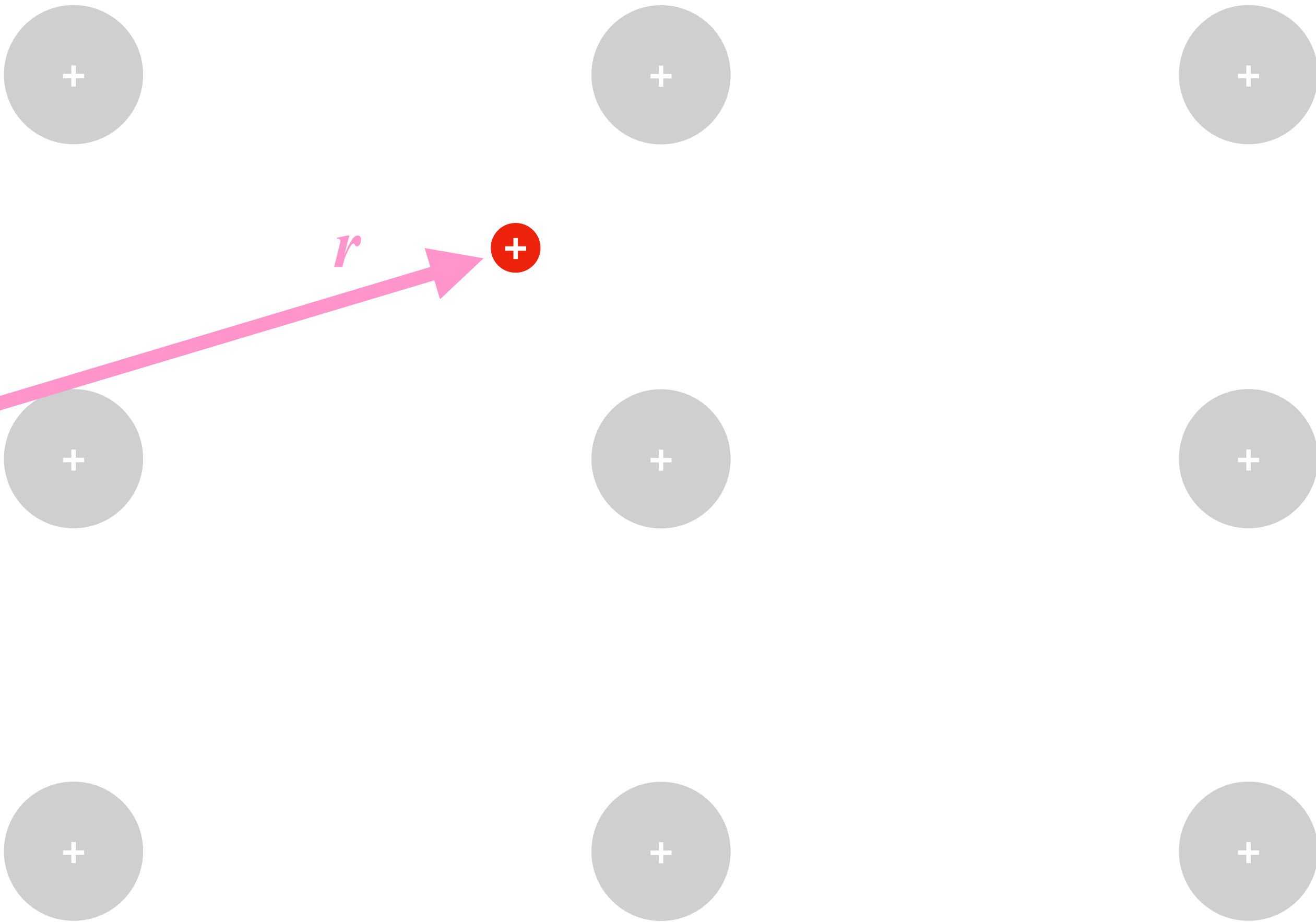
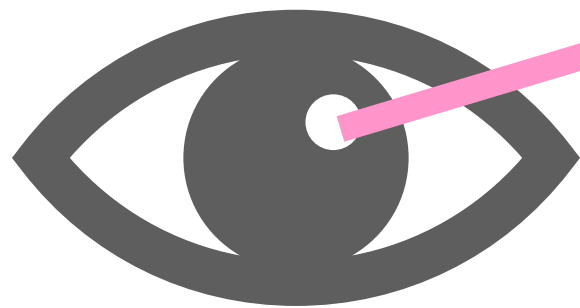


-  Ground-truth gaze position
-  Reported gaze position



Proposed Uncertainty Mitigation Algorithm: Interpolation 13 / 18

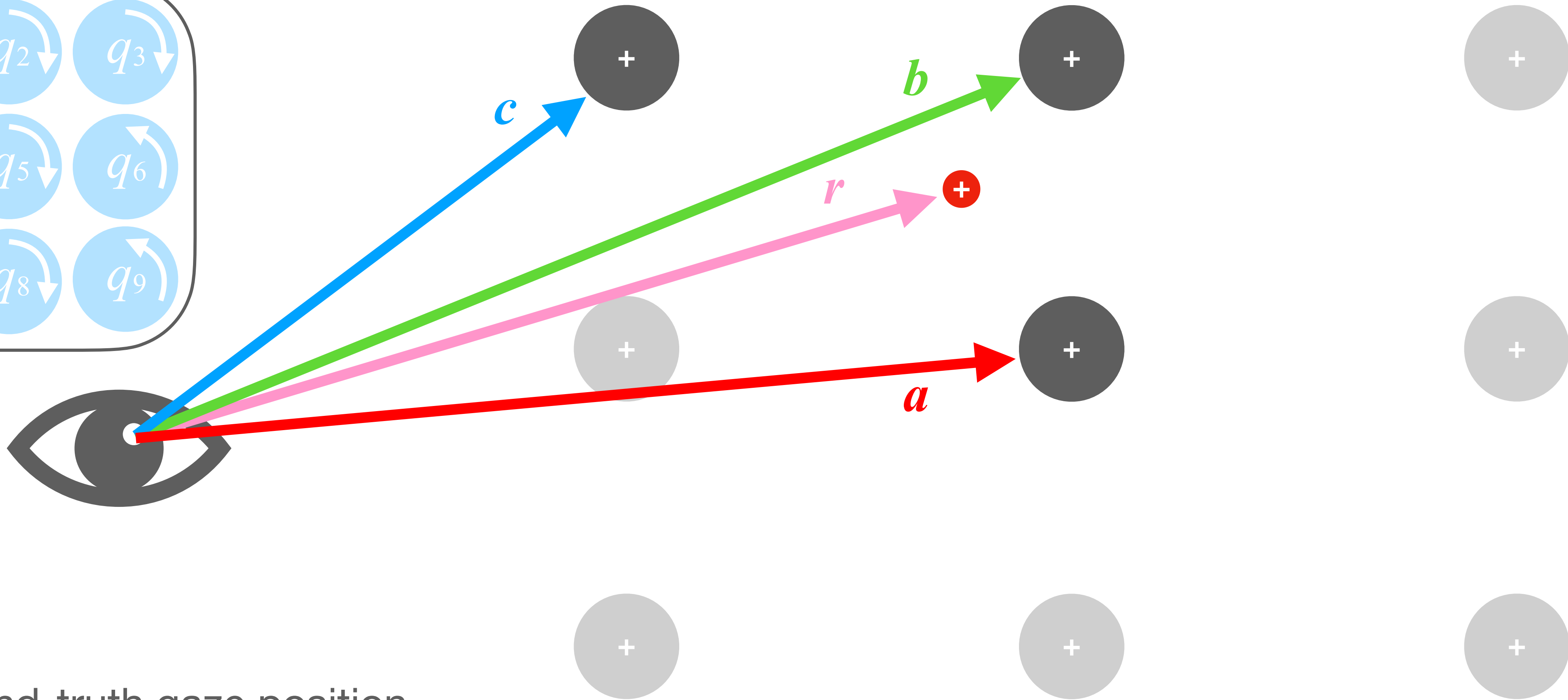
Reference quaternions



-  Ground-truth gaze position
-  Reported gaze position

Proposed Uncertainty Mitigation Algorithm: Interpolation 13 / 18

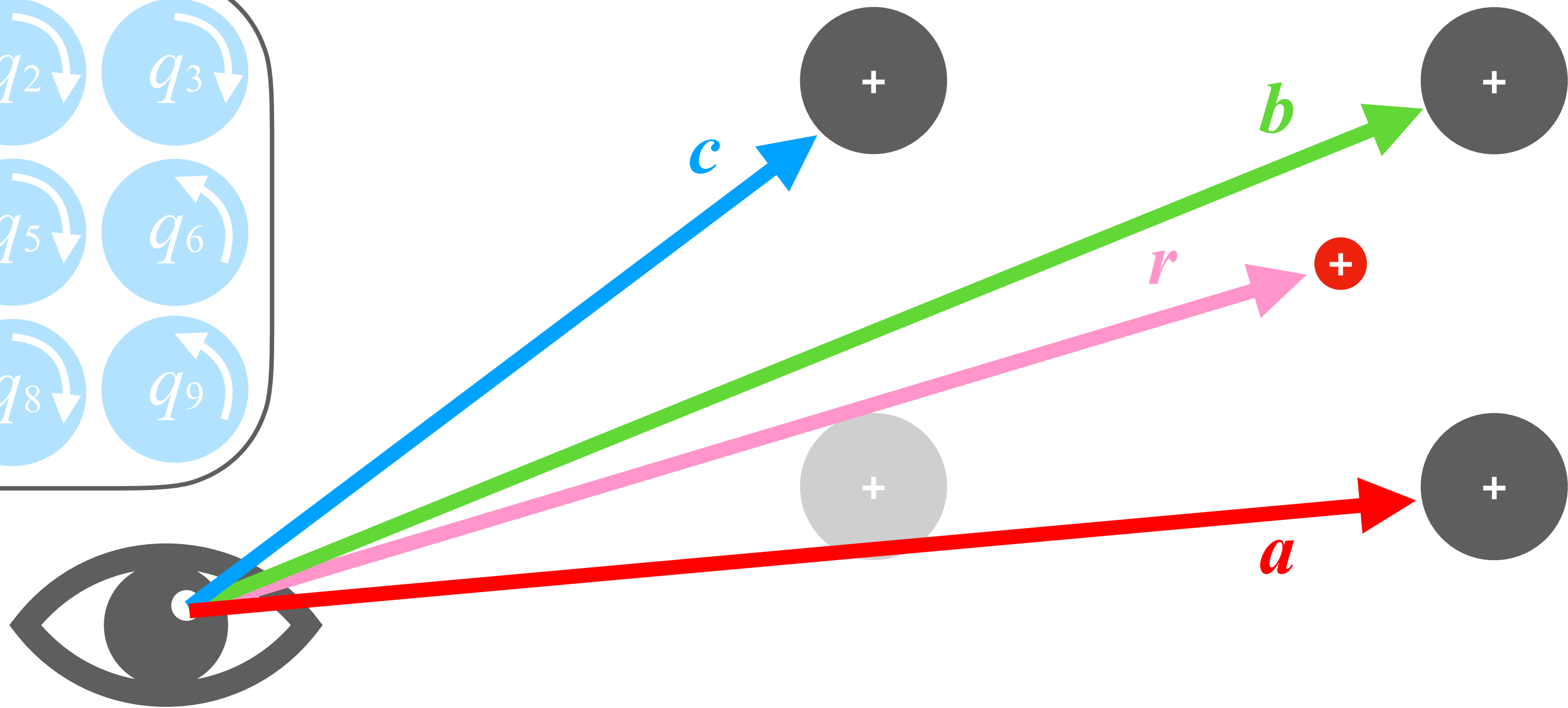
Reference quaternions



-  Ground-truth gaze position
-  Reported gaze position

Proposed Uncertainty Mitigation Algorithm: Interpolation 13 / 18

Reference quaternions

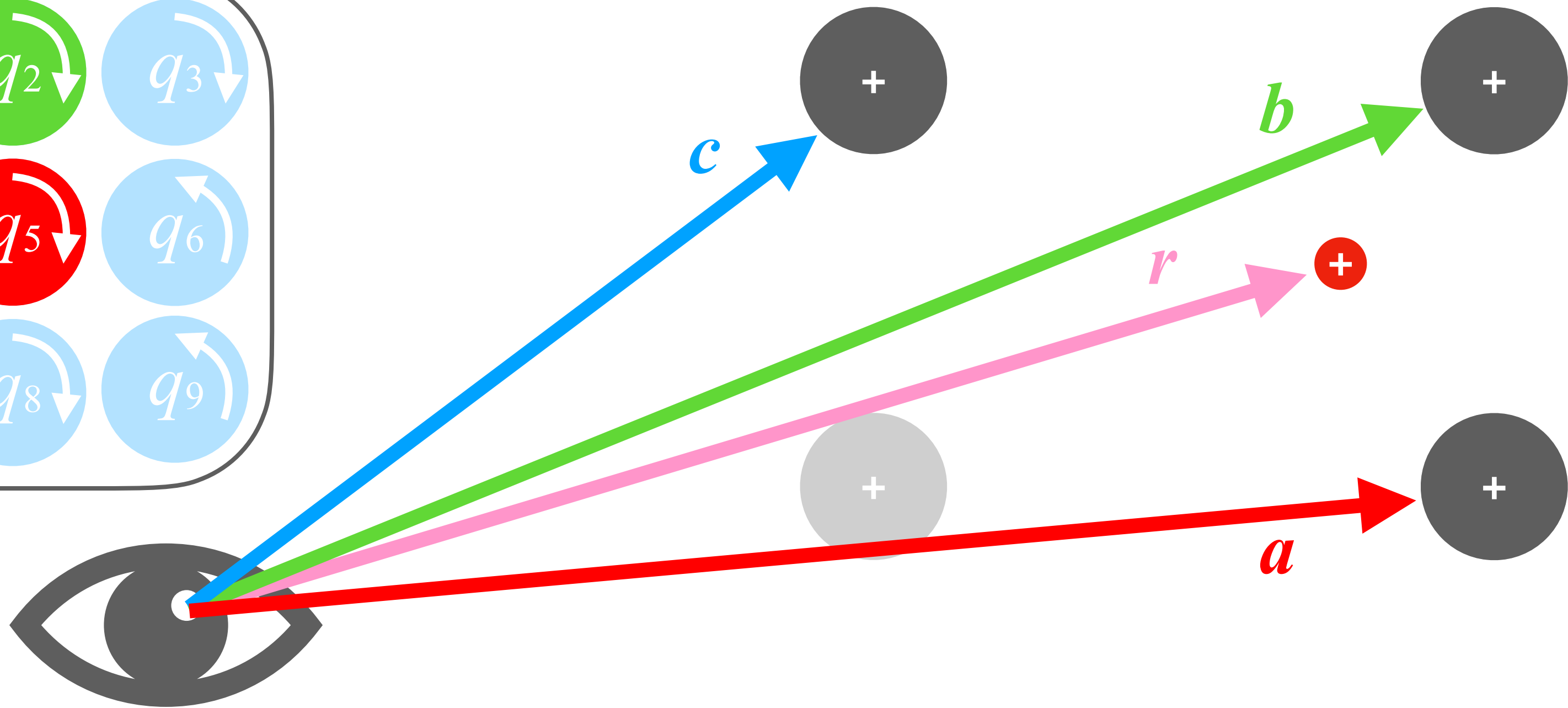


$$r = x \textcolor{red}{a} + y \textcolor{green}{b} + z \textcolor{blue}{c}$$

-  Ground-truth gaze position
-  Reported gaze position

Proposed Uncertainty Mitigation Algorithm: Interpolation 13 / 18

Reference quaternions

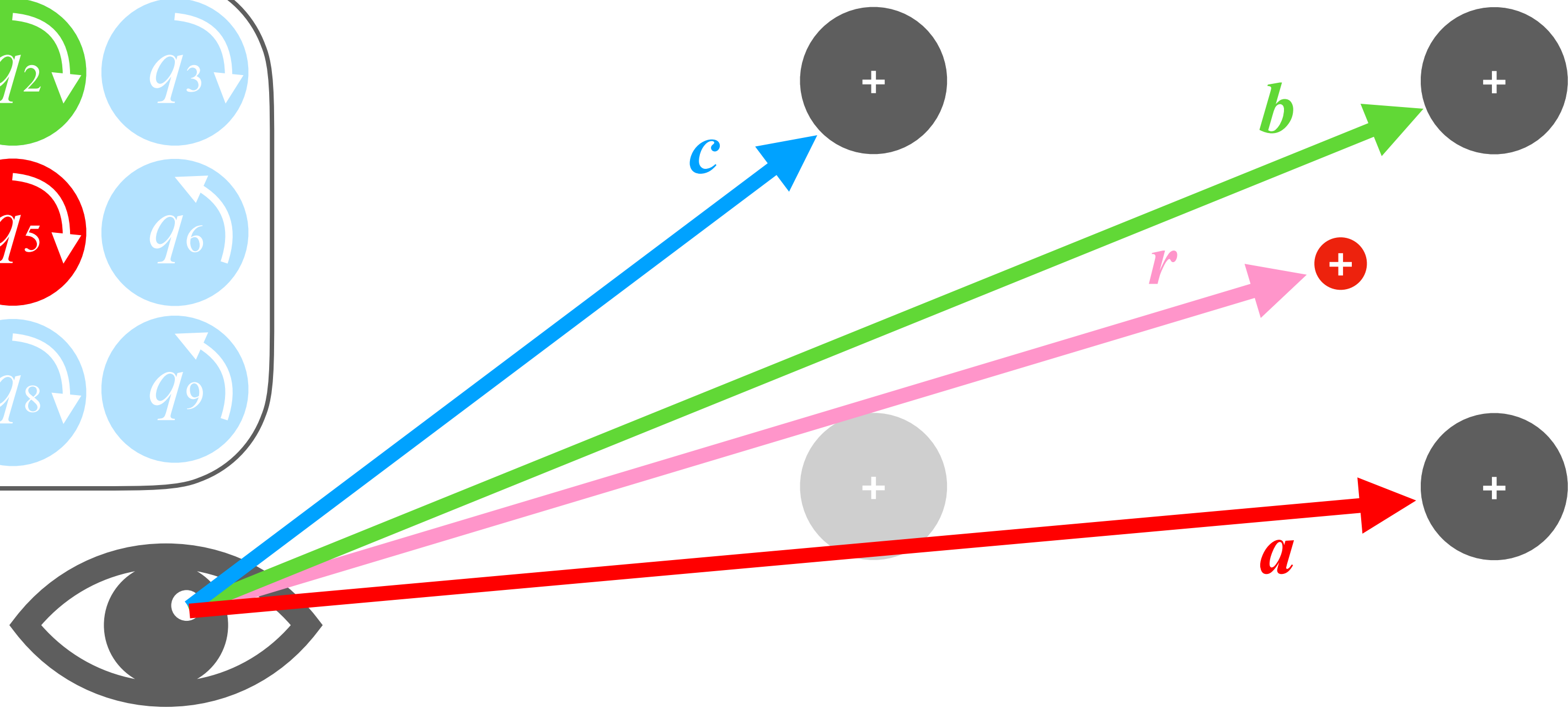


$$r = x \textcolor{red}{a} + y \textcolor{green}{b} + z \textcolor{blue}{c}$$

- Ground-truth gaze position
- Reported gaze position

Proposed Uncertainty Mitigation Algorithm: Interpolation 13 / 18

Reference quaternions

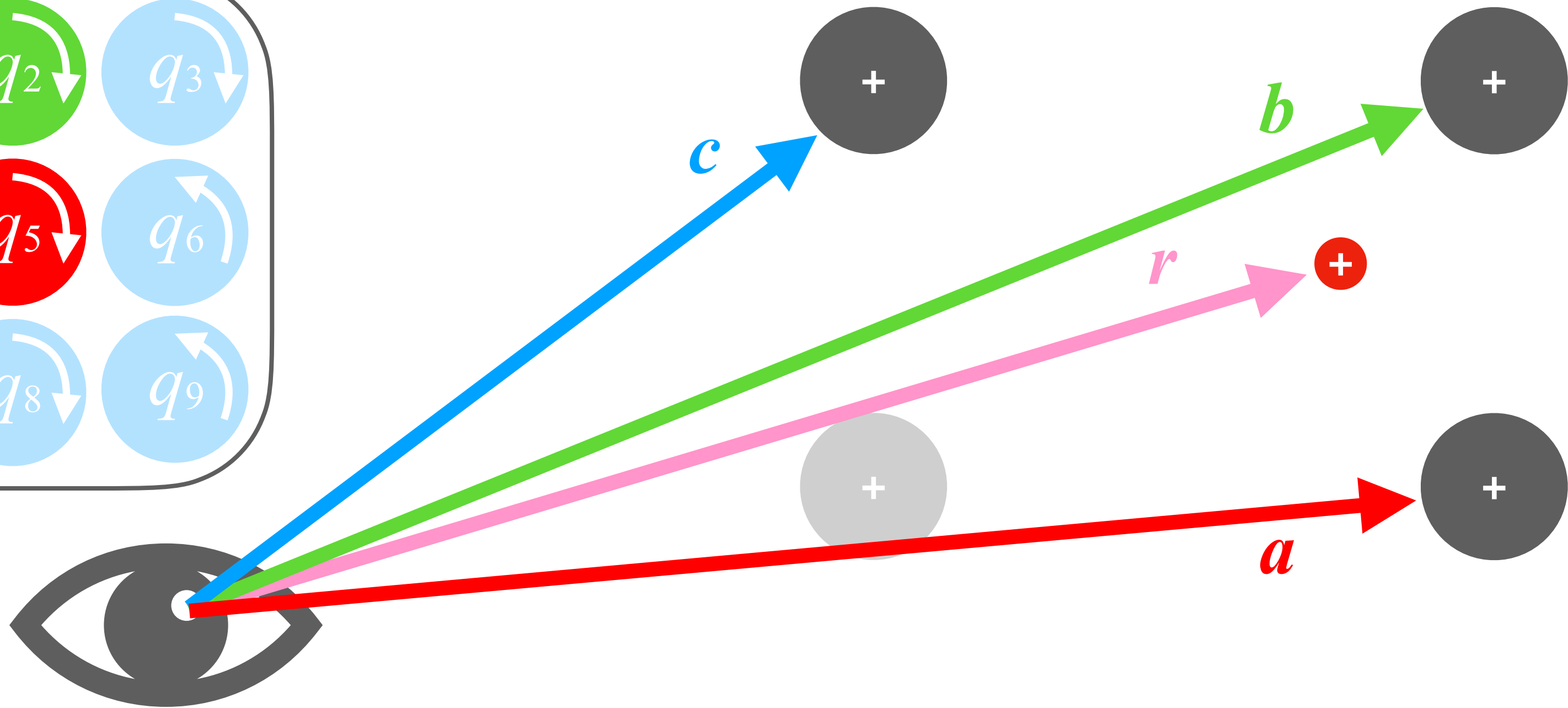


$$r = x a + y b + z c$$
$$q = x q_5 + y q_2 + z q_1$$

- + Ground-truth gaze position
- + Reported gaze position

Proposed Uncertainty Mitigation Algorithm: Interpolation 13 / 18

Reference quaternions

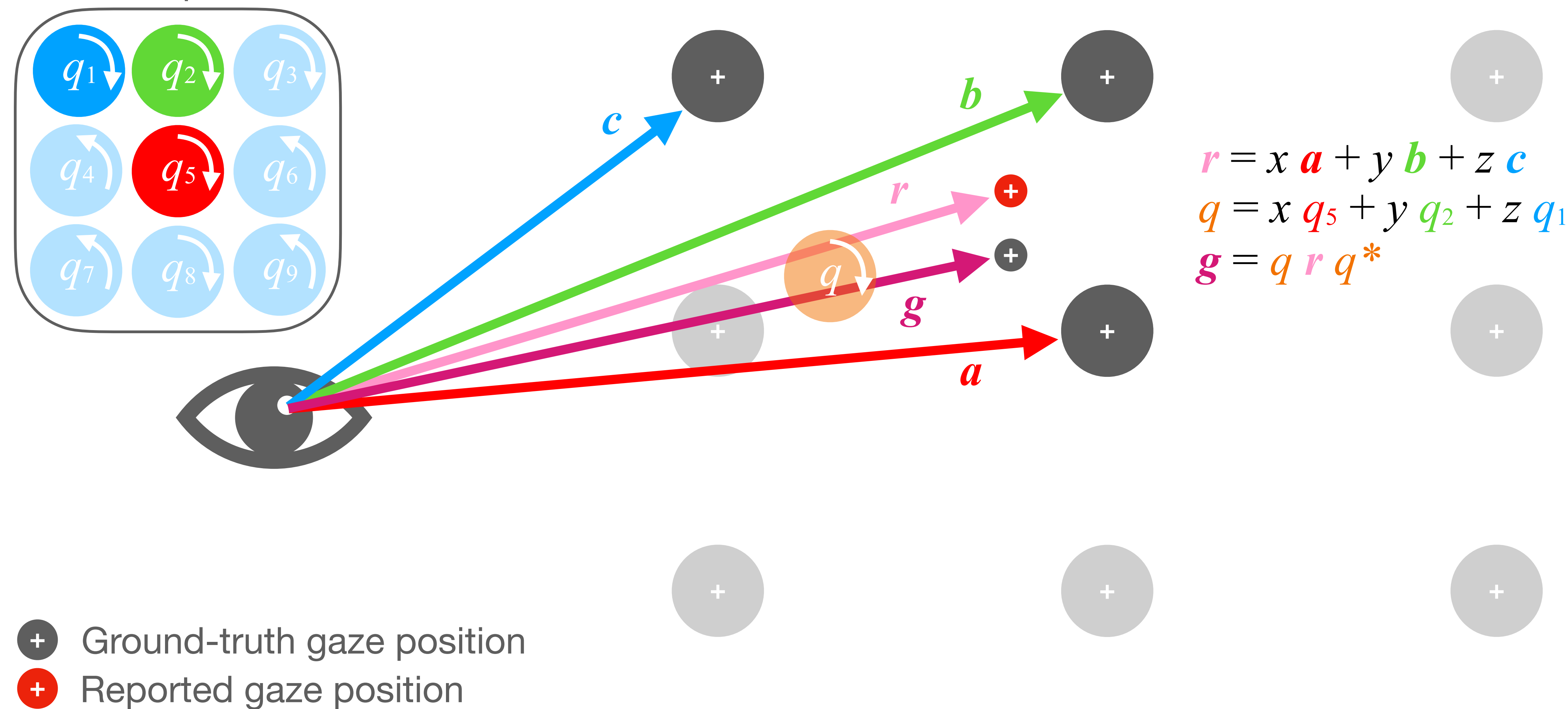


$$\begin{aligned} r &= x \mathbf{a} + y \mathbf{b} + z \mathbf{c} \\ q &= x \mathbf{q}_5 + y \mathbf{q}_2 + z \mathbf{q}_1 \\ g &= q \mathbf{r} q^* \end{aligned}$$

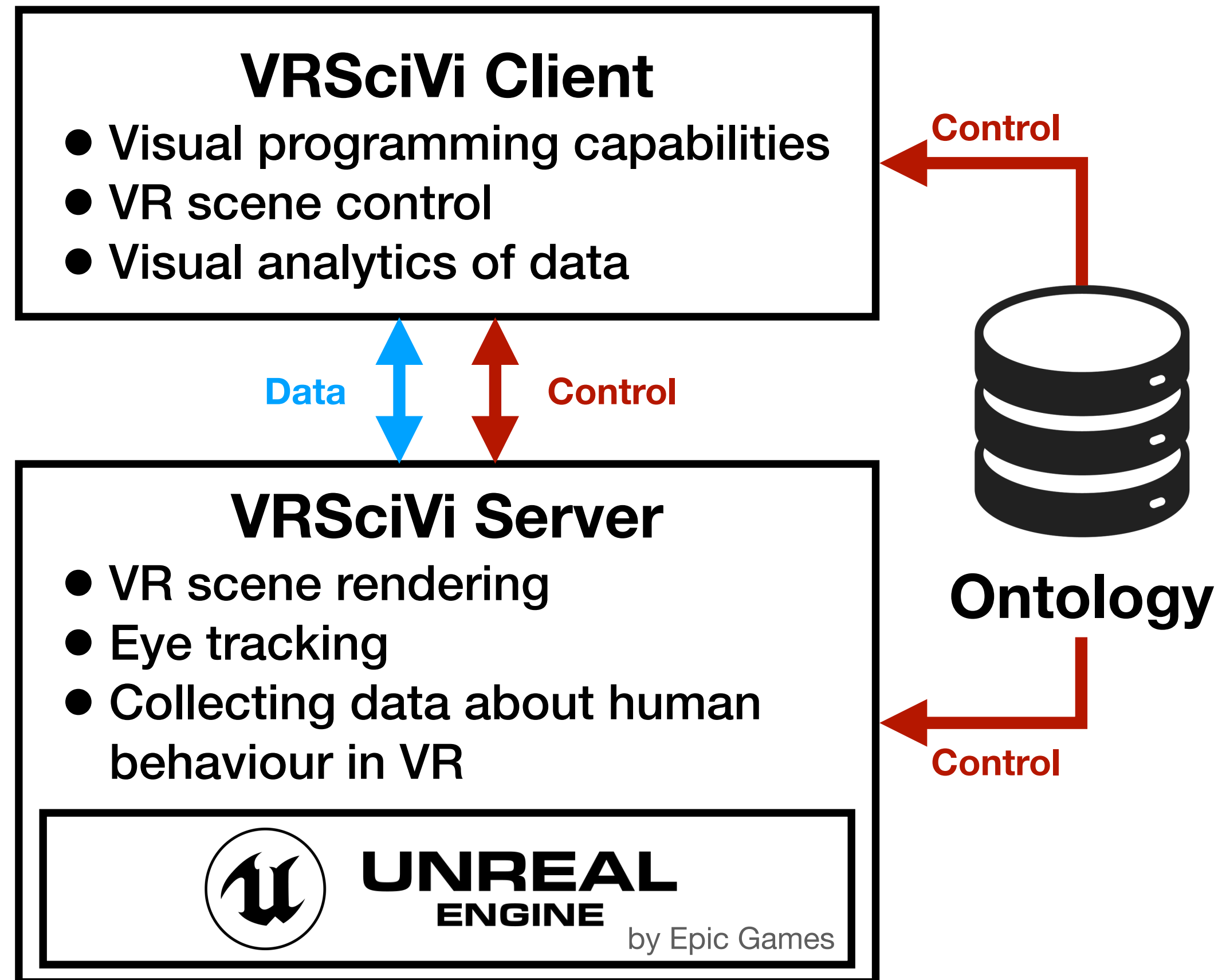
- Ground-truth gaze position
- Reported gaze position

Proposed Uncertainty Mitigation Algorithm: Interpolation 13 / 18

Reference quaternions



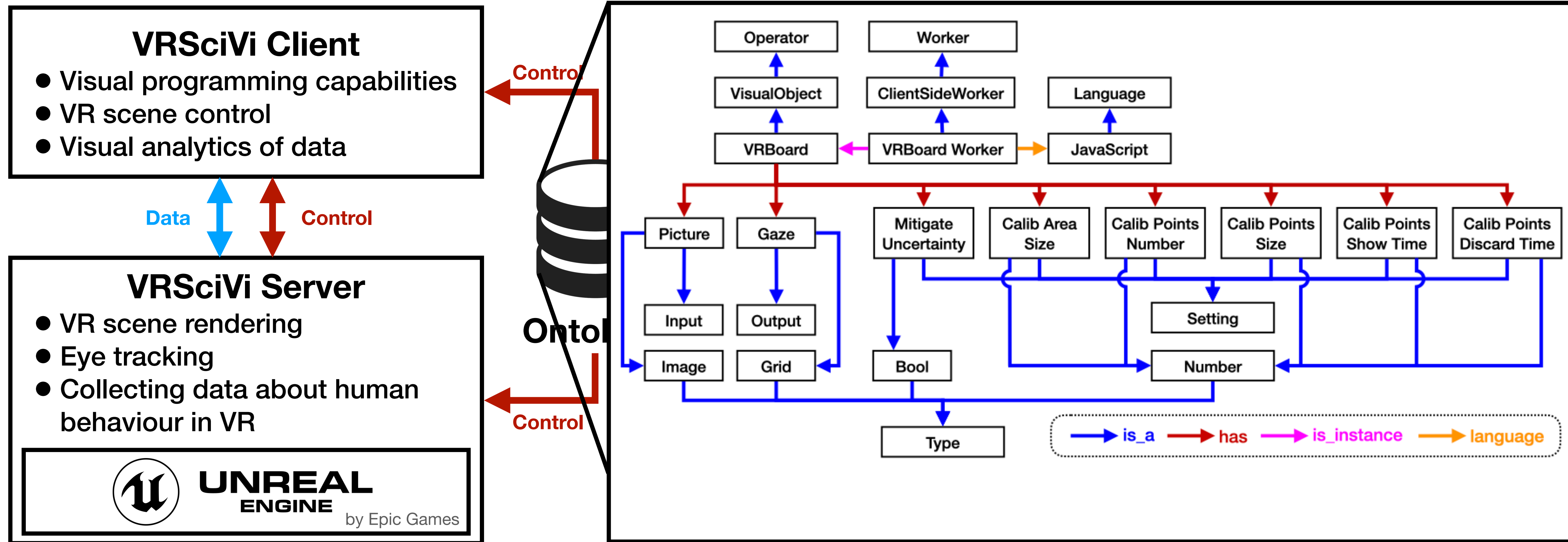
VRSciVi – ontology-driven workbench for conducting experiments in VR
(open source project, <https://scivi.tools/vrscivi>)



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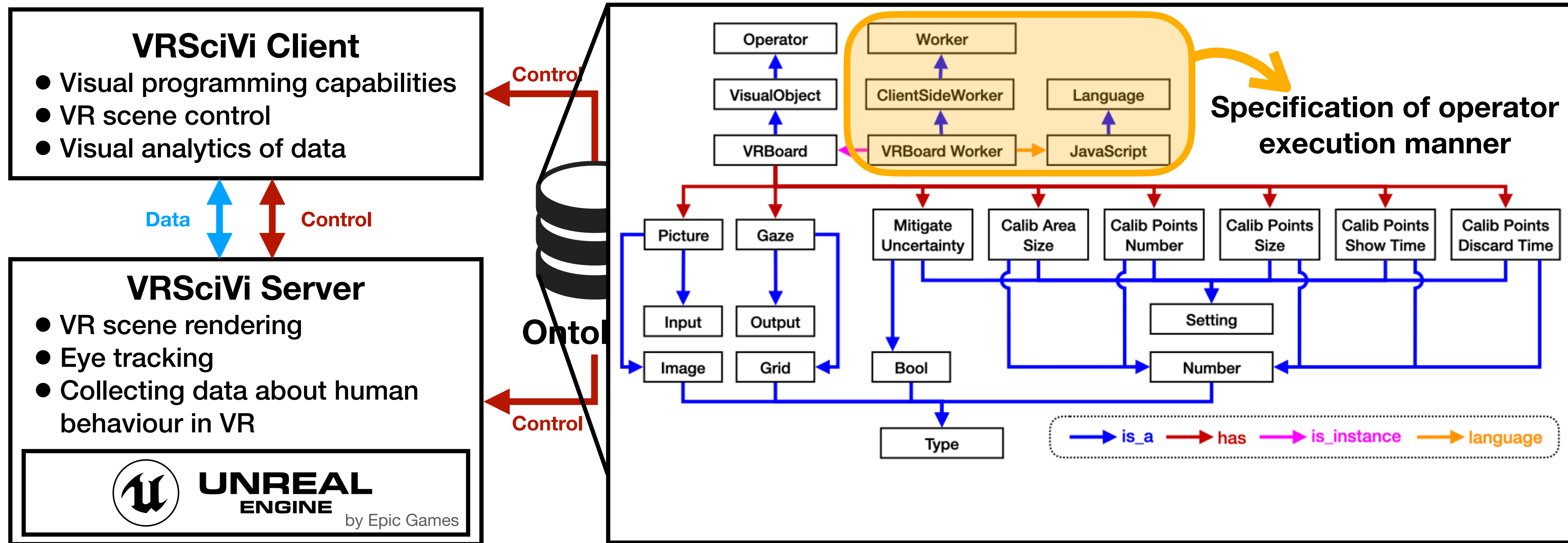
Ontology of an operator that controls VR scenes



VRSciVi – ontology-driven workbench for conducting experiments in VR

(open source project, <https://scivi.tools/vrscivi>)

Ontology of an operator that controls VR scenes



(open source project, <https://scivi.tools/vrscivi>)

The diagram illustrates the architecture of the VRSciVi system, divided into two main components: the VRSciVi Client and the VRSciVi Server.

VRSciVi Client:

- Visual programming capabilities
- VR scene control
- Visual analytics of data

VRSciVi Server:

- VR scene rendering
- Eye tracking
- Collecting data about human behaviour in VR

The client and server are connected via a central **Ontology** component, which is represented by a cylinder. The connection is bidirectional, with **Data** flow (blue double-headed arrow) and **Control** flow (red double-headed arrow).

Internal Structure of the VRSciVi Server:

The server's internal structure is detailed in the right-hand diagram, showing the flow of data and control between various components:

- Operator** (top level) interacts with **VisualObject** and **VRBoard**.
- VisualObject** interacts with **VRBoard**.
- VRBoard** interacts with **Picture** and **Gaze**.
- Picture** and **Gaze** interact with **Input** and **Output**.
- Input** and **Output** interact with **Image** and **Grid**.
- Image** and **Grid** interact with **Bool** and **Number**.
- Bool** and **Number** interact with **Type**.
- Worker** (top level) interacts with **ClientSideWorker** and **Language**.
- ClientSideWorker** interacts with **VRBoard Worker** and **JavaScript**.
- VRBoard Worker** interacts with **JavaScript**.
- VRBoard Worker** interacts with **Mitigate Uncertainty**, **Calib Area Size**, **Calib Points Number**, **Calib Points Size**, **Calib Points Show Time**, and **Calib Points Discard Time**.
- Mitigate Uncertainty**, **Calib Area Size**, **Calib Points Number**, **Calib Points Size**, **Calib Points Show Time**, and **Calib Points Discard Time** interact with **Setting** and **Number**.
- Setting** and **Number** interact with **Type**.

The diagram also includes a legend for the types of arrows used:

- is_a** (blue arrow)
- has** (red arrow)
- is_instance** (pink arrow)
- language** (orange arrow)

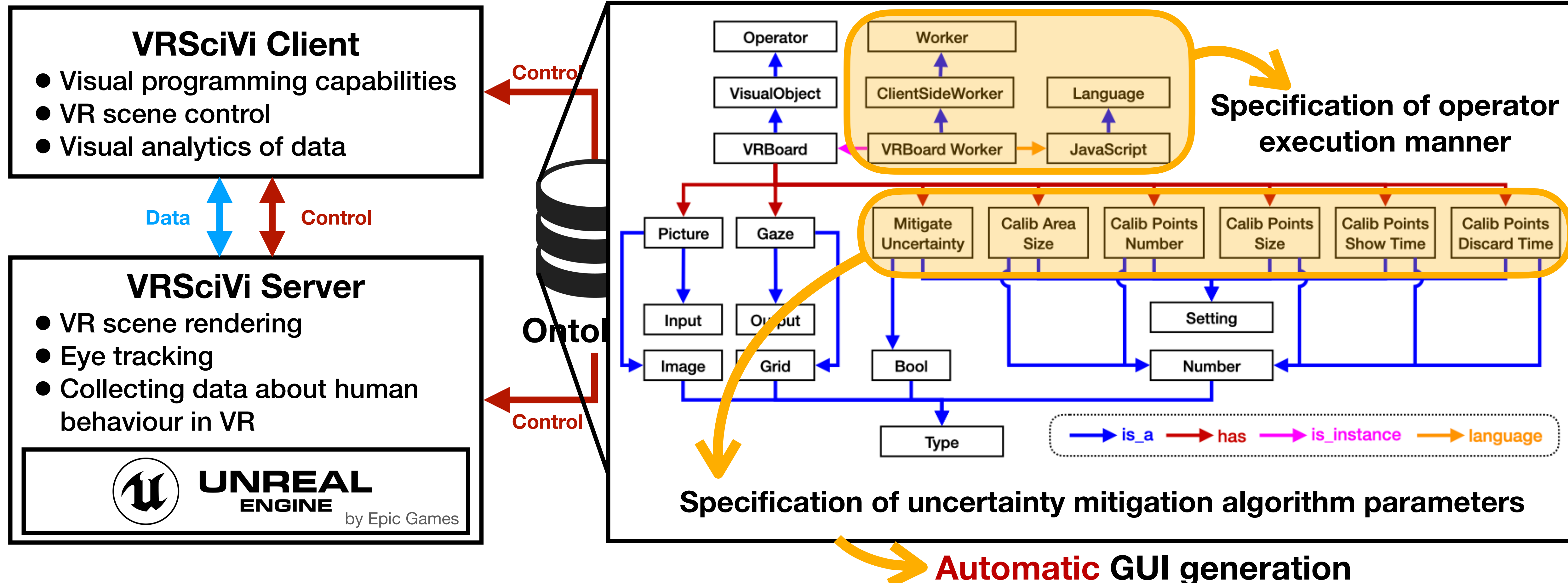
Two large yellow arrows point from the internal structure to the text labels:

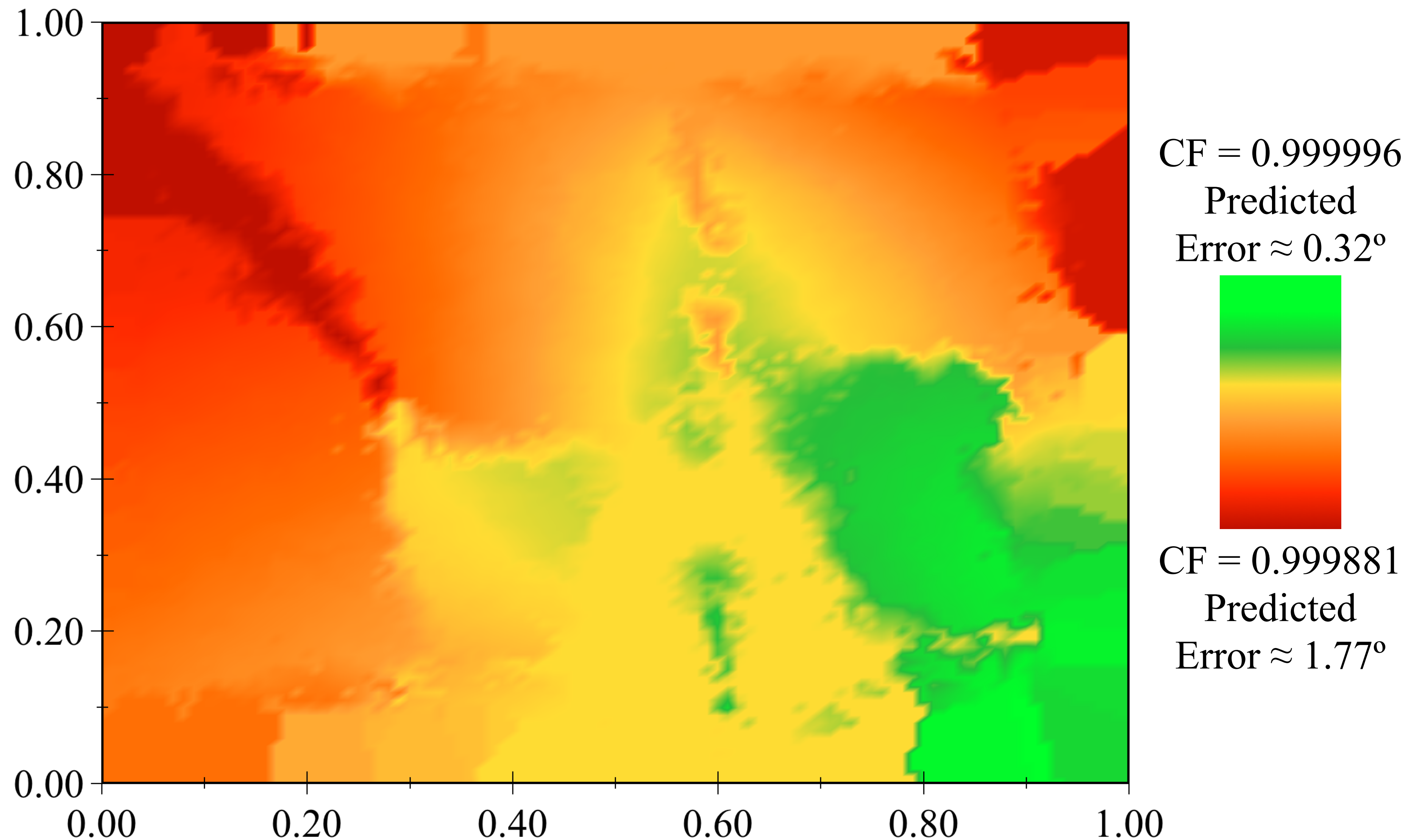
- Specification of operator execution manner** (pointing to the Worker/ClientSideWorker/JavaScript area).
- Specification of uncertainty mitigation algorithm parameters** (pointing to the Mitigate Uncertainty/Calib... area).

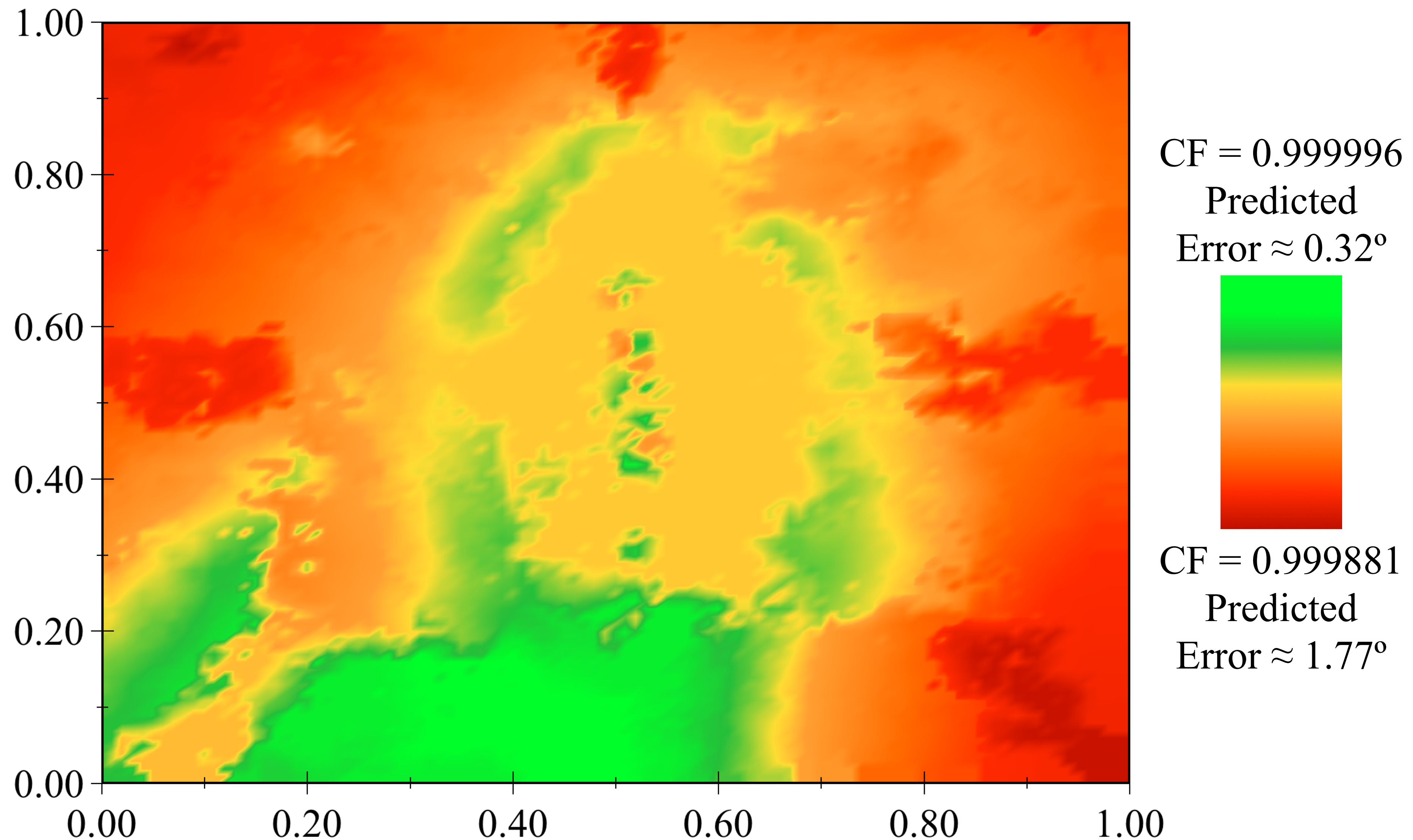
VRSciVi – ontology-driven workbench for conducting experiments in VR

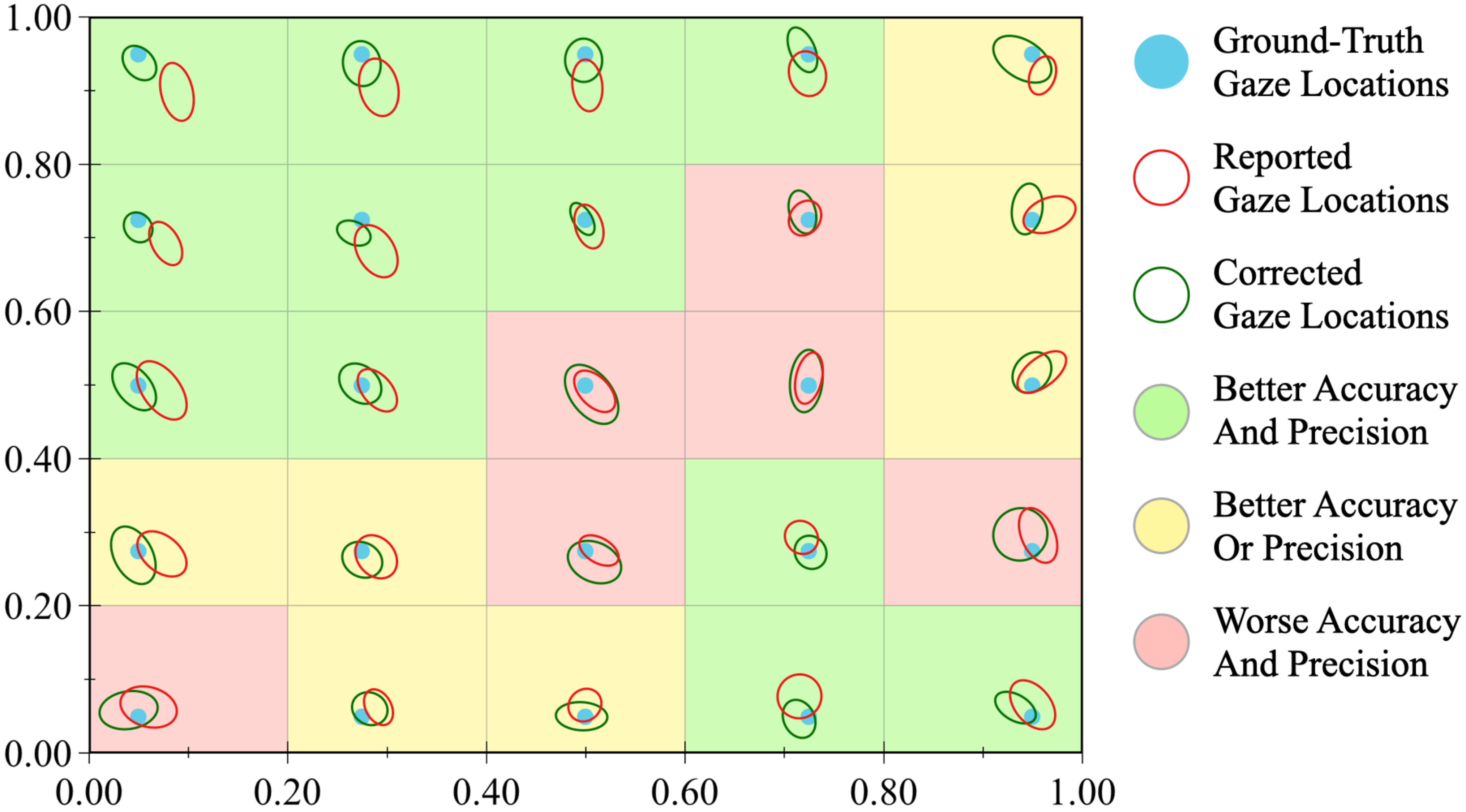
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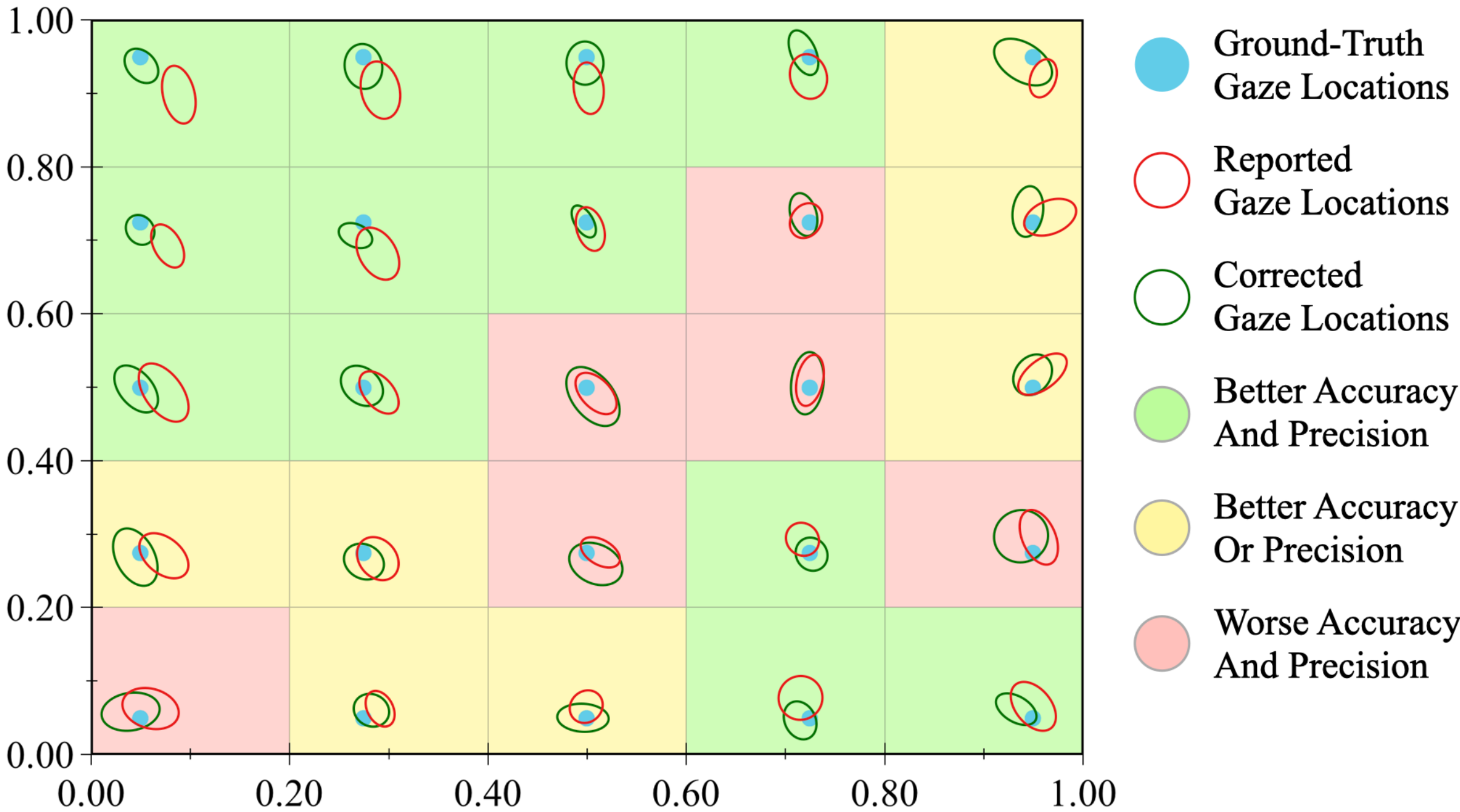
Ontology of an operator that controls VR scenes











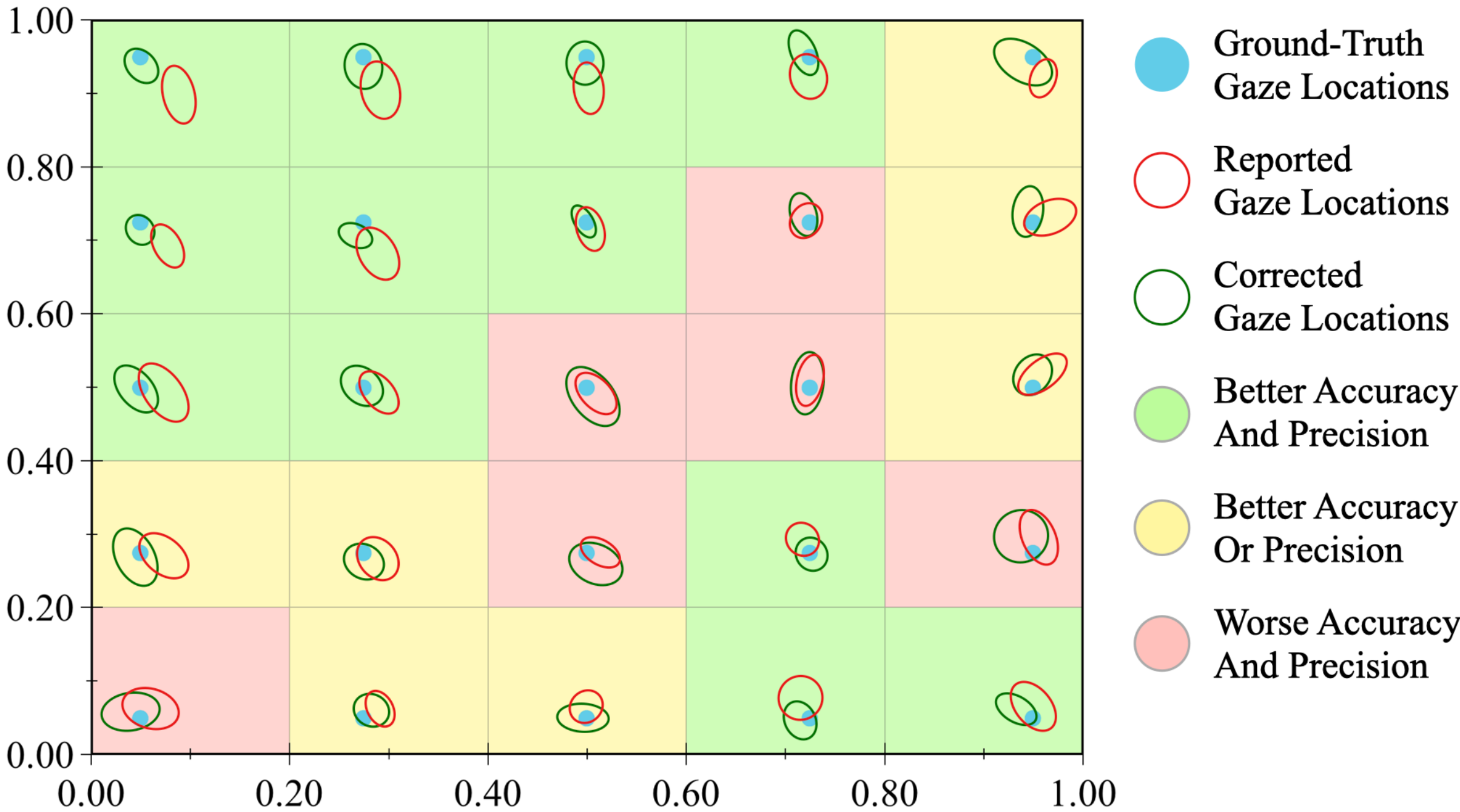
Angular error of gaze positions

Without mitigation:



With mitigation:





Angular error of gaze positions

Without mitigation:



With mitigation:



Key results:

1. Novel quaternion-based model of the eye gaze tracking uncertainty
2. Novel algorithm to mitigate the eye gaze tracking uncertainty at runtime
accuracy +25%, precision +32%
3. Ontology-driven high-level software development tools to generate the interface for parametrization of the proposed algorithm

Outstanding issue:

~30% better – still not enough to study reading

Future work:

Involving machine learning for interpolating quaternions

1



St Petersburg
University

2



Perm State
University

Thank you for attention!

This study is supported by the research grant
No. ID75288744 from Saint Petersburg University,
"Text processing in L1 and L2: Experimental study
with eye-tracking, visual analytics and virtual reality
technologies"

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Perm-London – 2022