Unified Motion Planner for **Fishes** with **Various Swimming Styles**

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Underwater scene - *various* and *many* fish

Why is it difficult to reproduce underwater scenes?

- 1. Swimming styles of fish are very diverse

Variation of swimming styles
by fish species

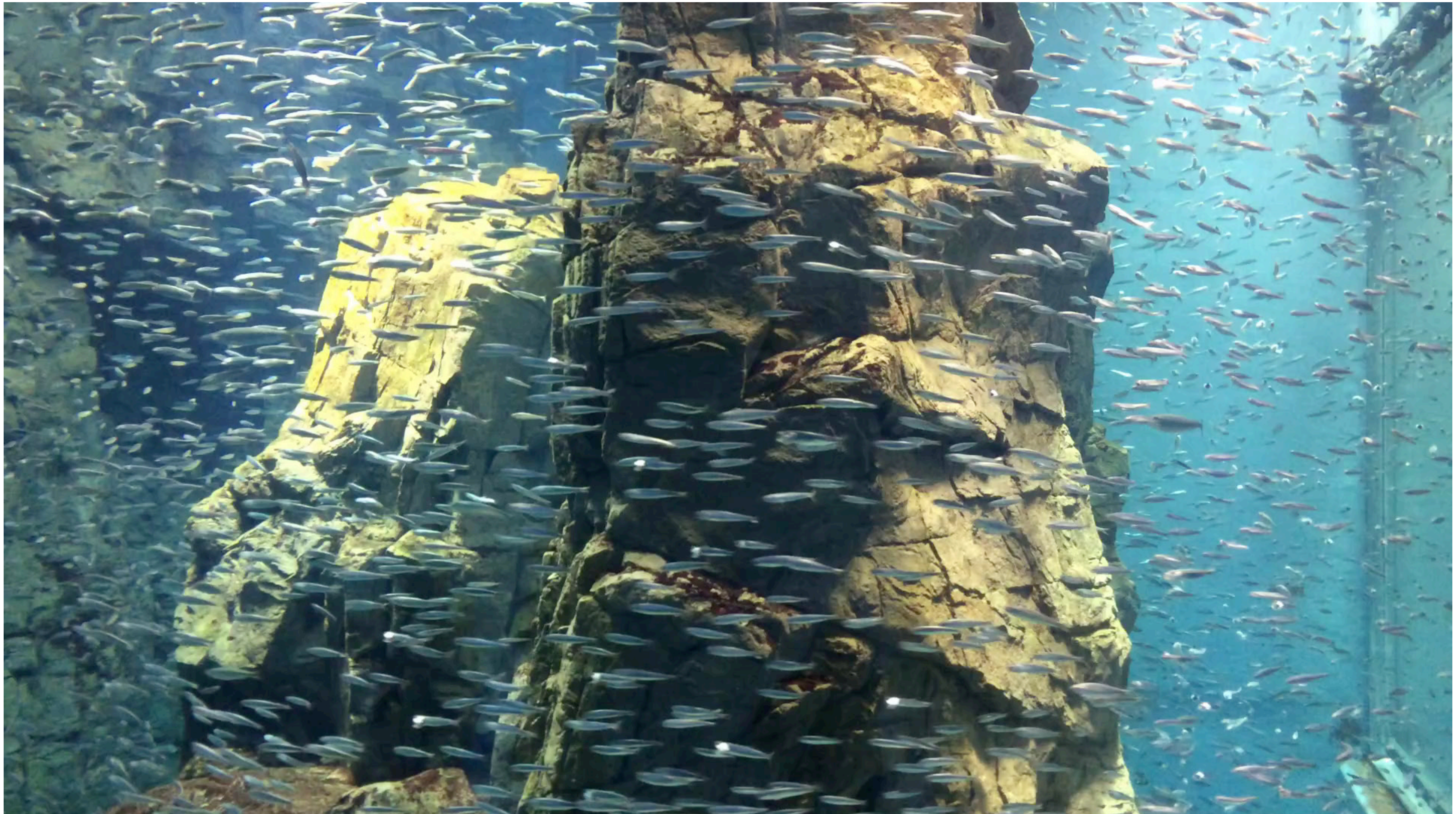
- 28,000+ species
- Big difference of size and skeleton structure

Variation of swimming styles
by change of a situation

- e.g.
  swim *slowly* -> oscillate pectoral fins
  swim *rapidly* -> undulate body trunk

Why is it difficult to reproduce underwater scenes?

- 2. Number of fish is very large

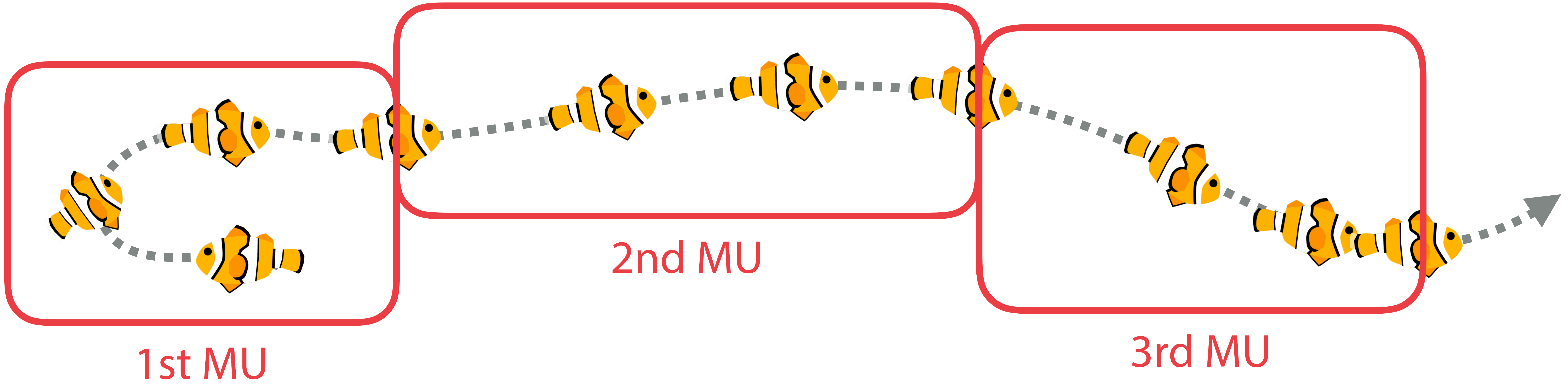


Research question

- How to reproduce…
  - realistic and massive fishes
  - with various swimming styles
  - by fish species and change of a situation?

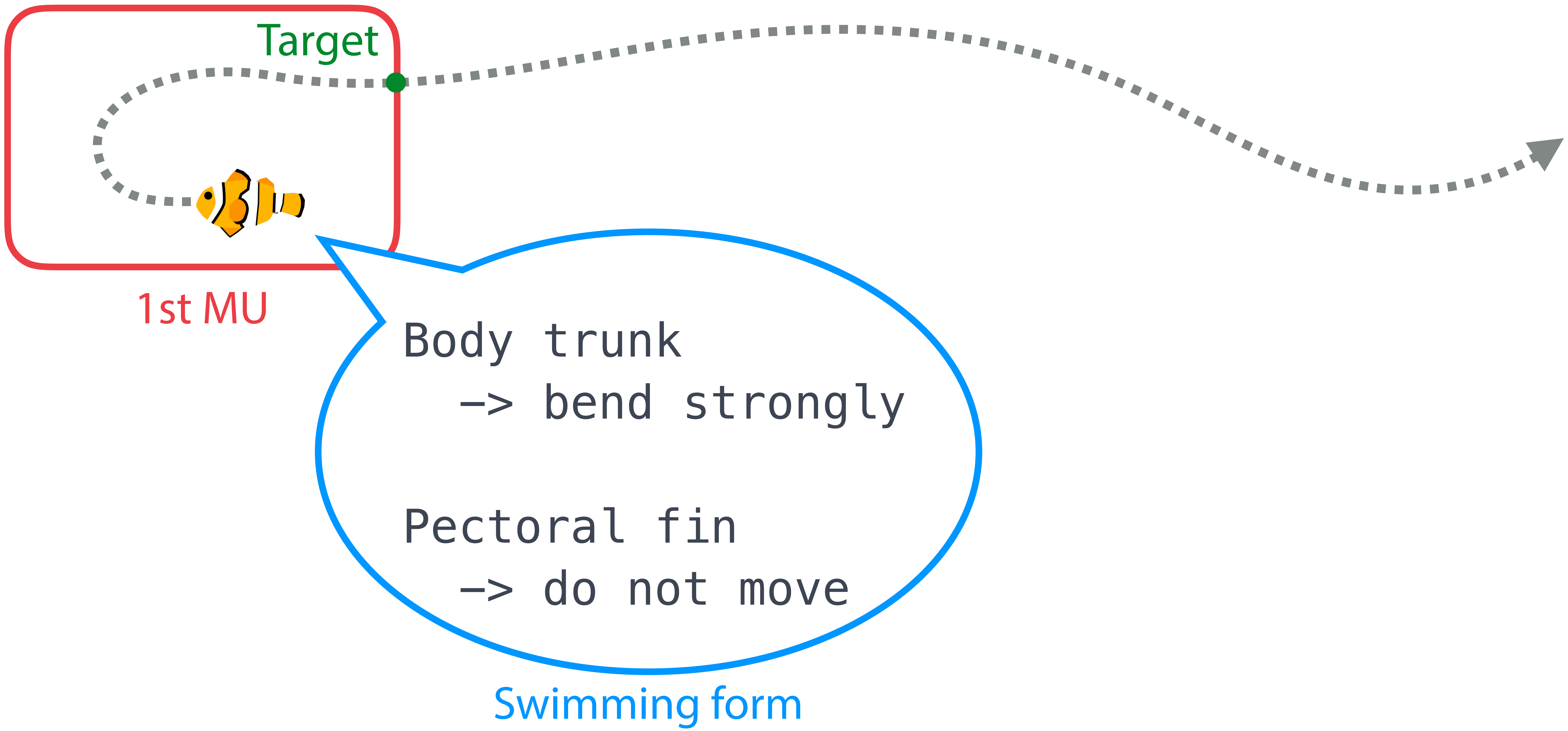
Our approach

- Resolve swimming motion into Motion Unit



Our approach

- Resolve swimming motion into Motion Unit
  Decide "where to swim" and "how to swim"



Our approach

- Resolve swimming motion into Motion Unit
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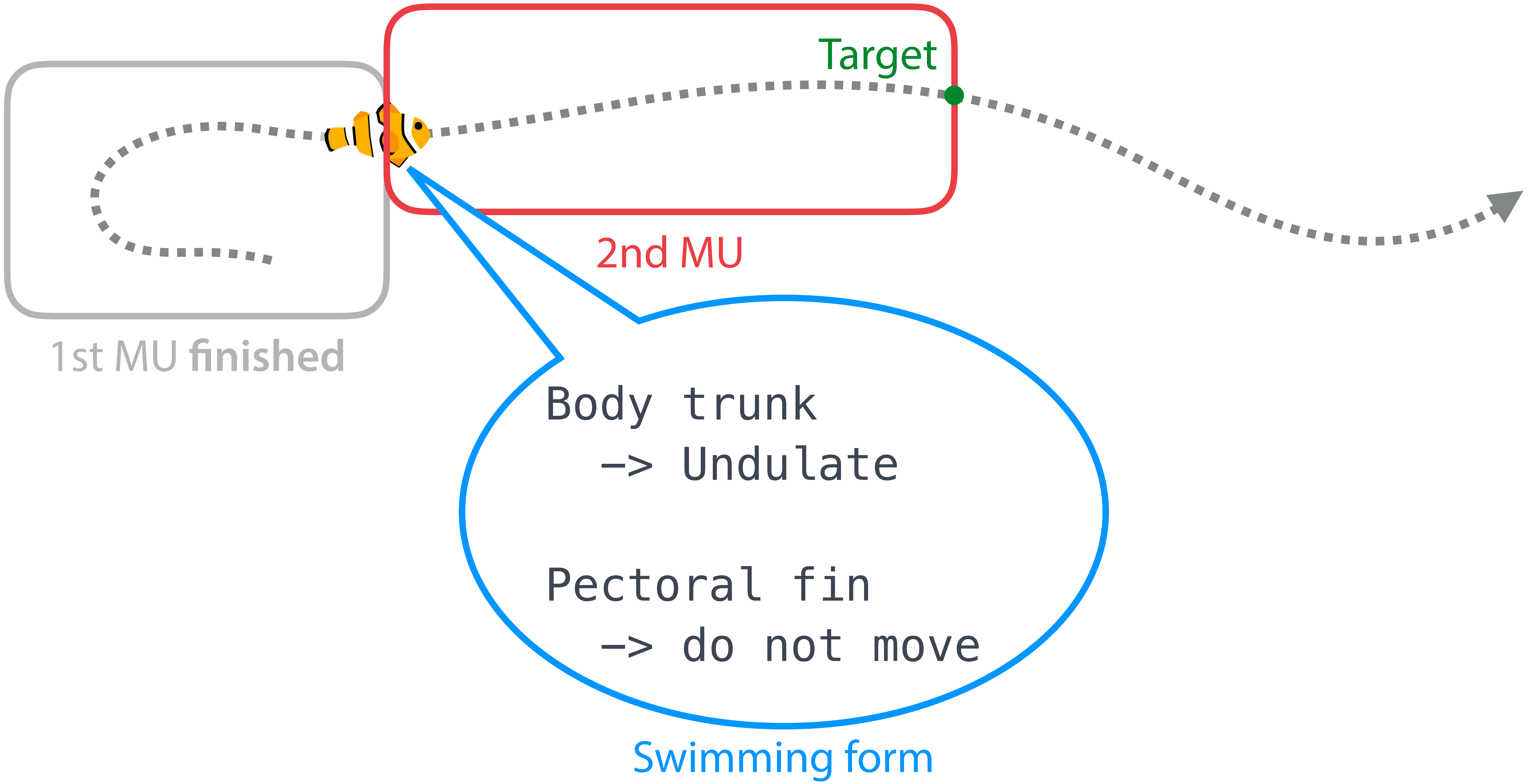
Our approach

- Resolve swimming motion into Motion Unit
  Decide “where to swim“ and “how to swim” repeatedly



Our approach

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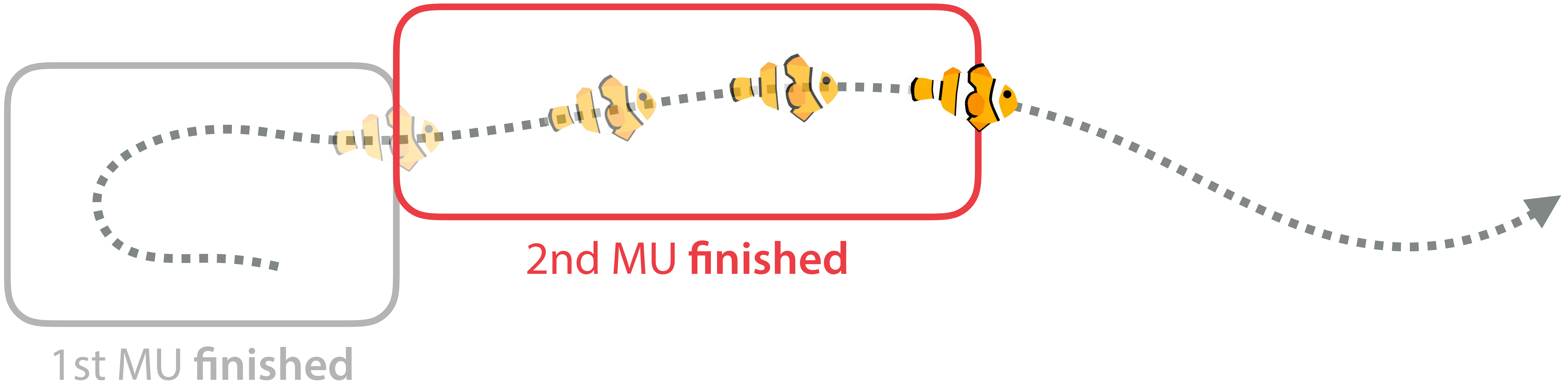

Our approach

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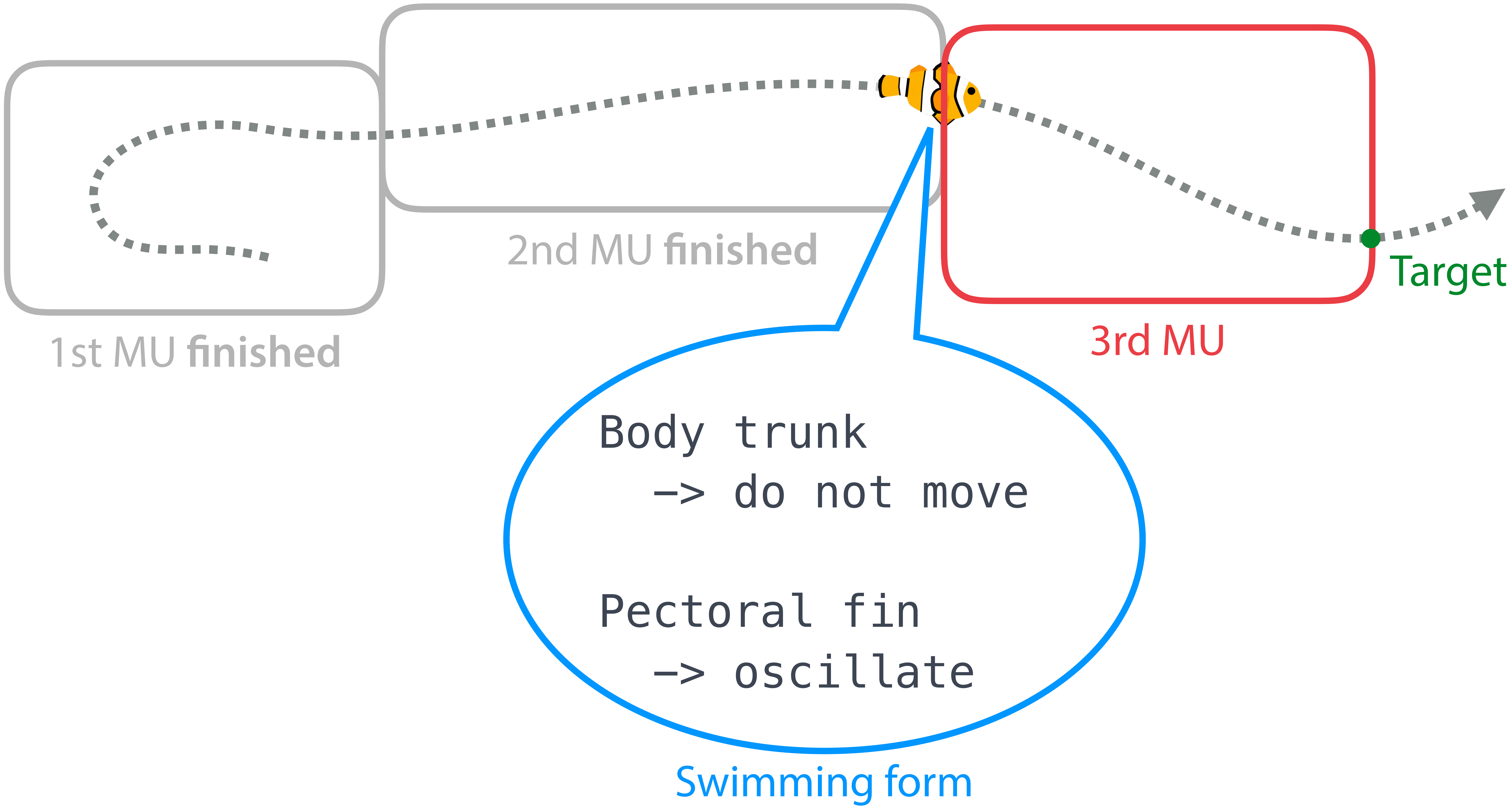
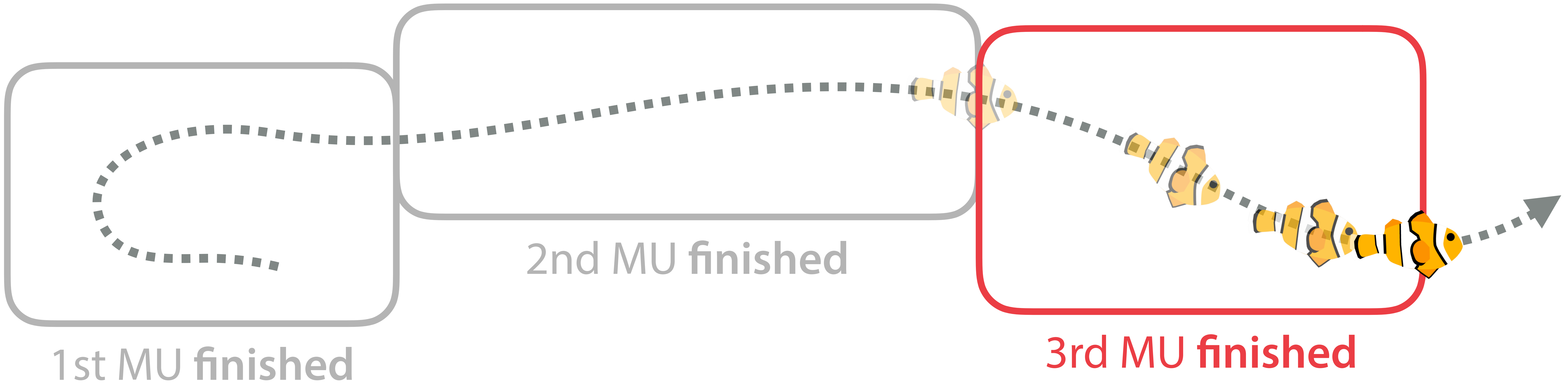


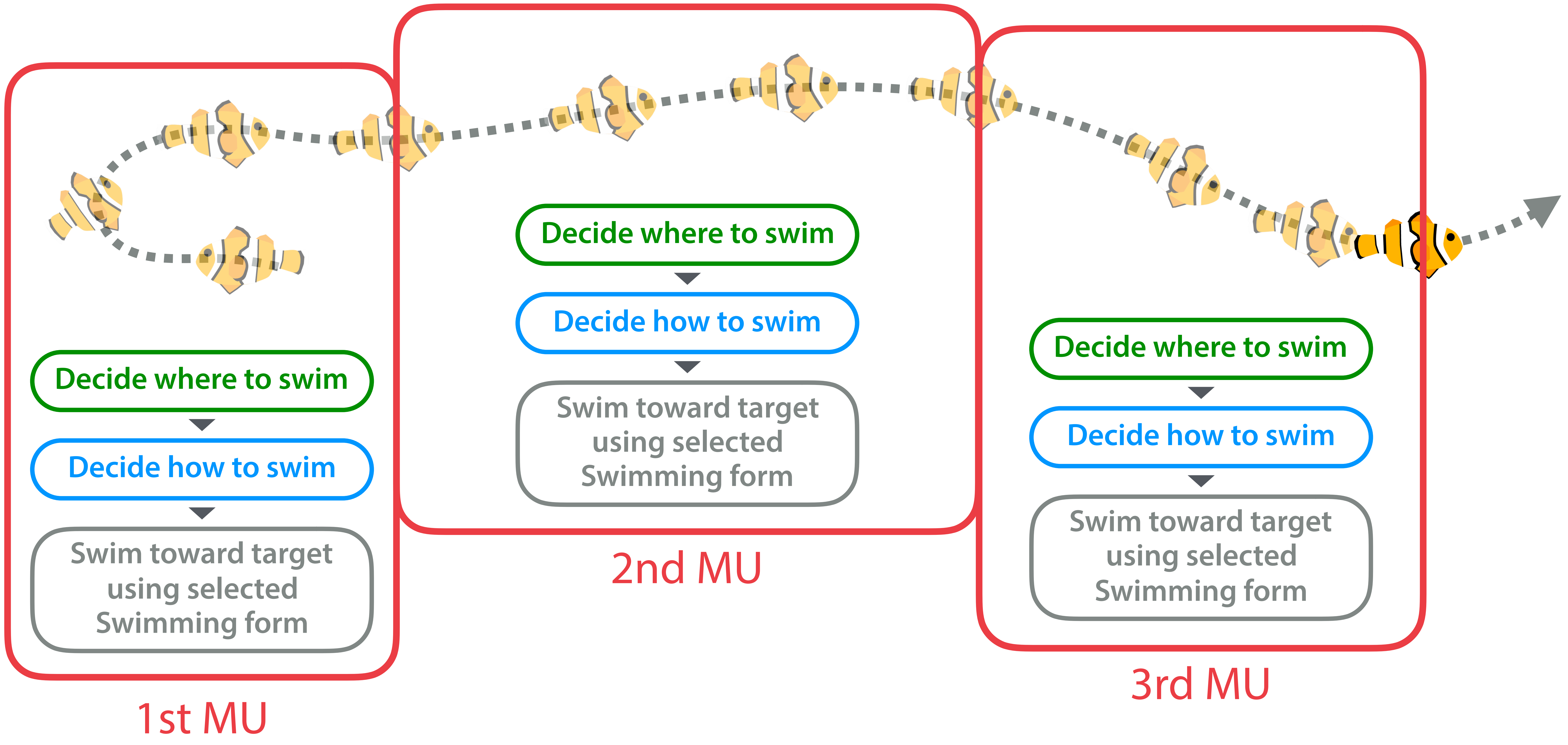
Our approach

- Resolve swimming motion into Motion Unit
  Decide "where to swim" and "how to swim" repeatedly



Our approach

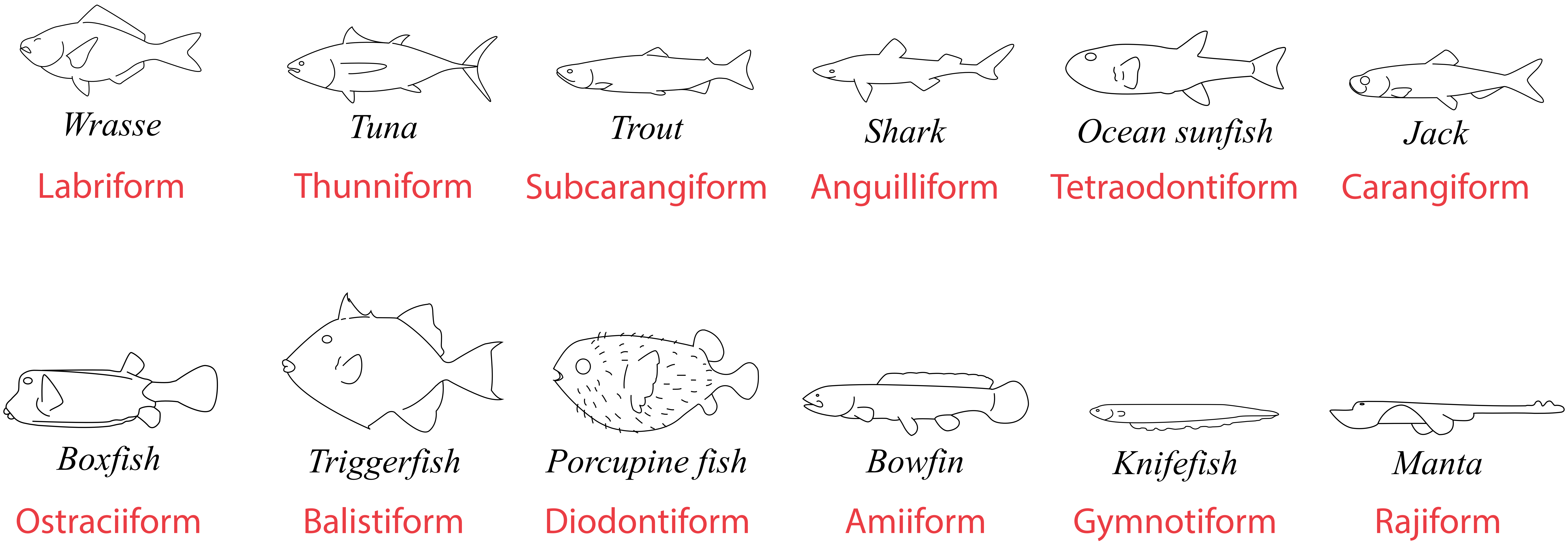
- Resolve swimming motion into Motion Unit
  Decide “where to swim“ and “how to swim” repeatedly



Resolve swimming motion of fish

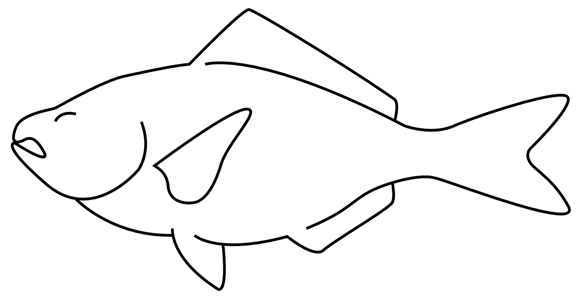
28,000+ species

- Categorized as 12 Swimming modes in fish physiology *[Lindsey 1978]*



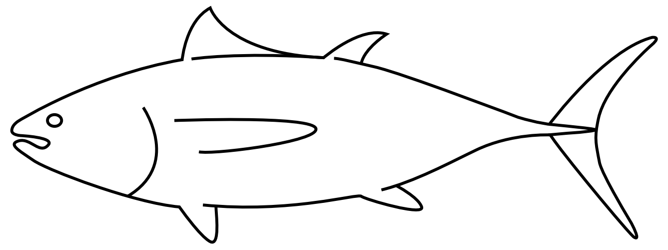
What is the difference?

- Skeleton structure



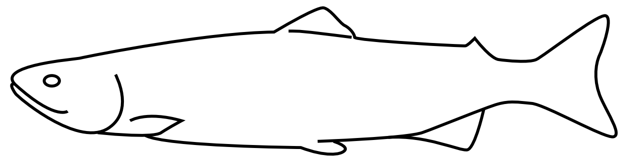
Wrasse

Labriform



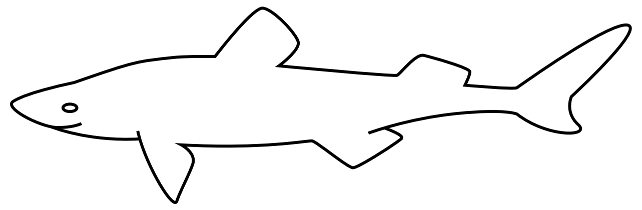
Tuna

Thunniform



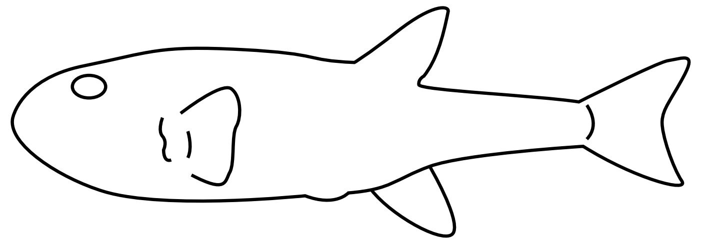
Trout

Subcarangiform



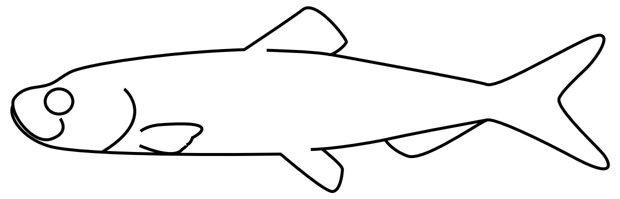
Shark

Anguilliform



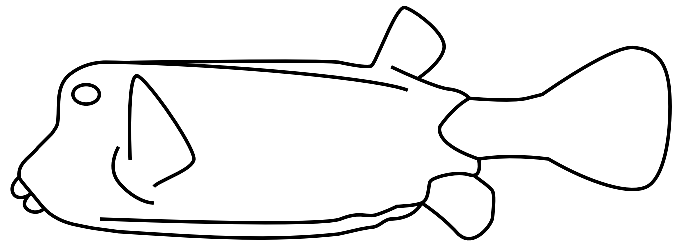
Ocean sunfish

Tetraodontiform



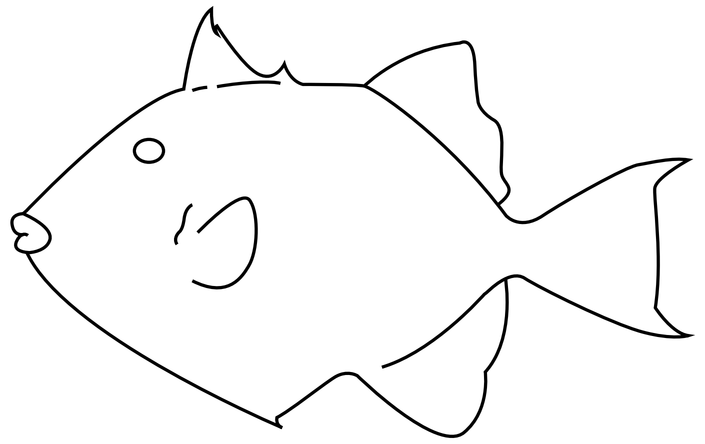
Jack

Carangiform



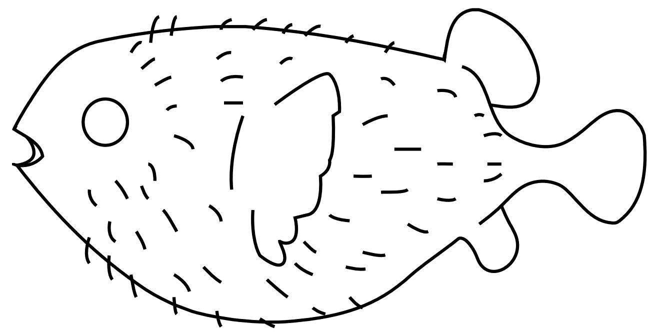
Boxfish

Ostraciiform



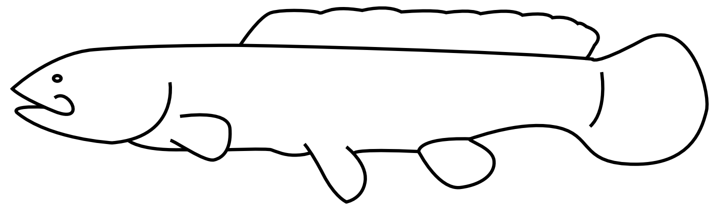
Triggerfish

Balistiform



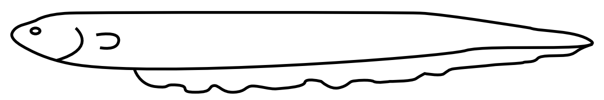
Porcupine fish

Diodontiform



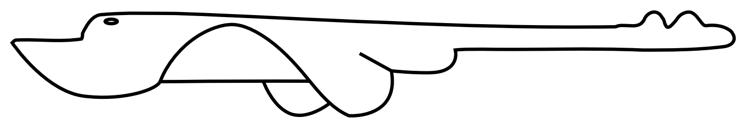
Bowfin

Amiiform



Knifefish

Gymnotiform

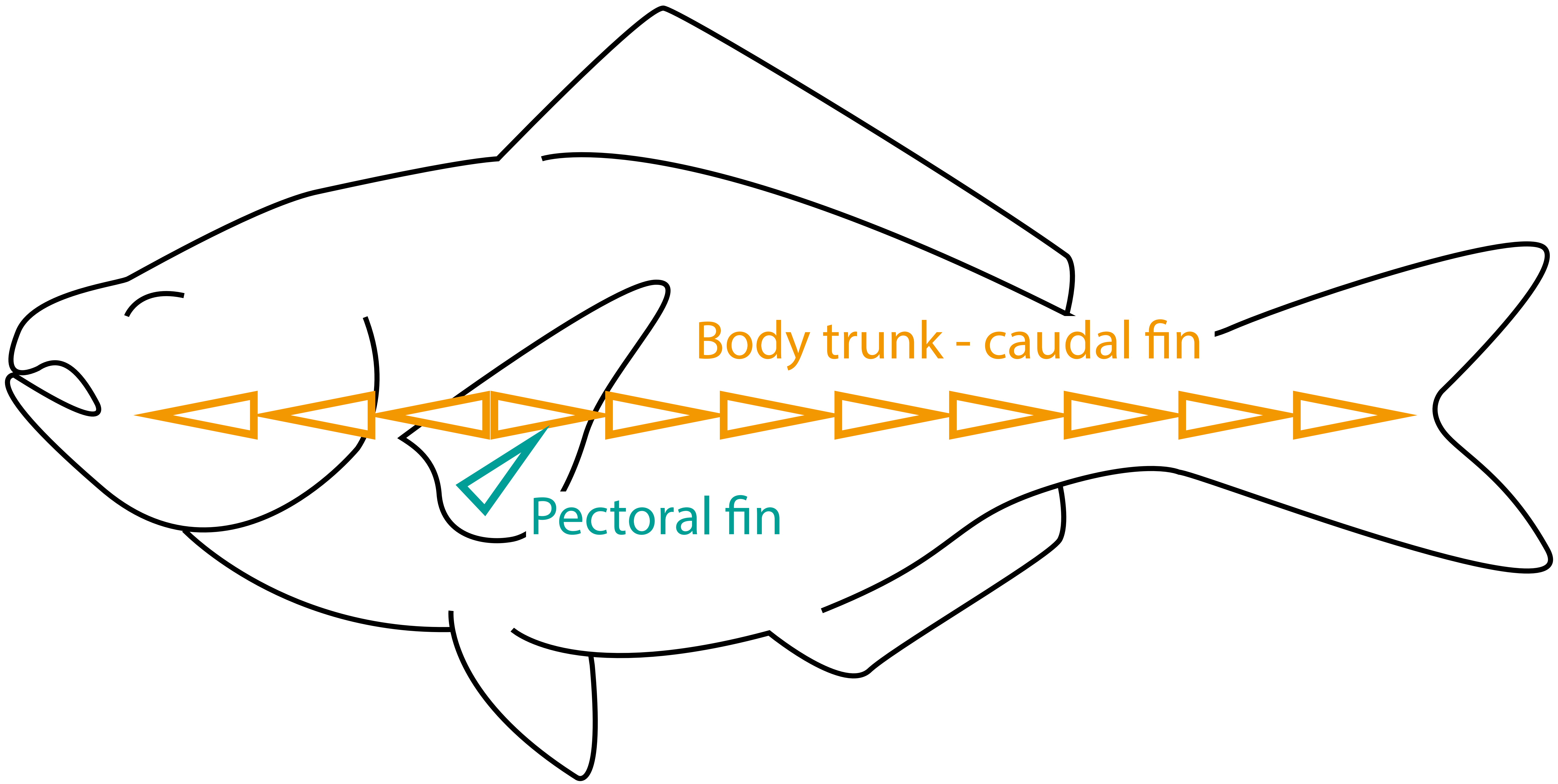


Manta

Rajiform

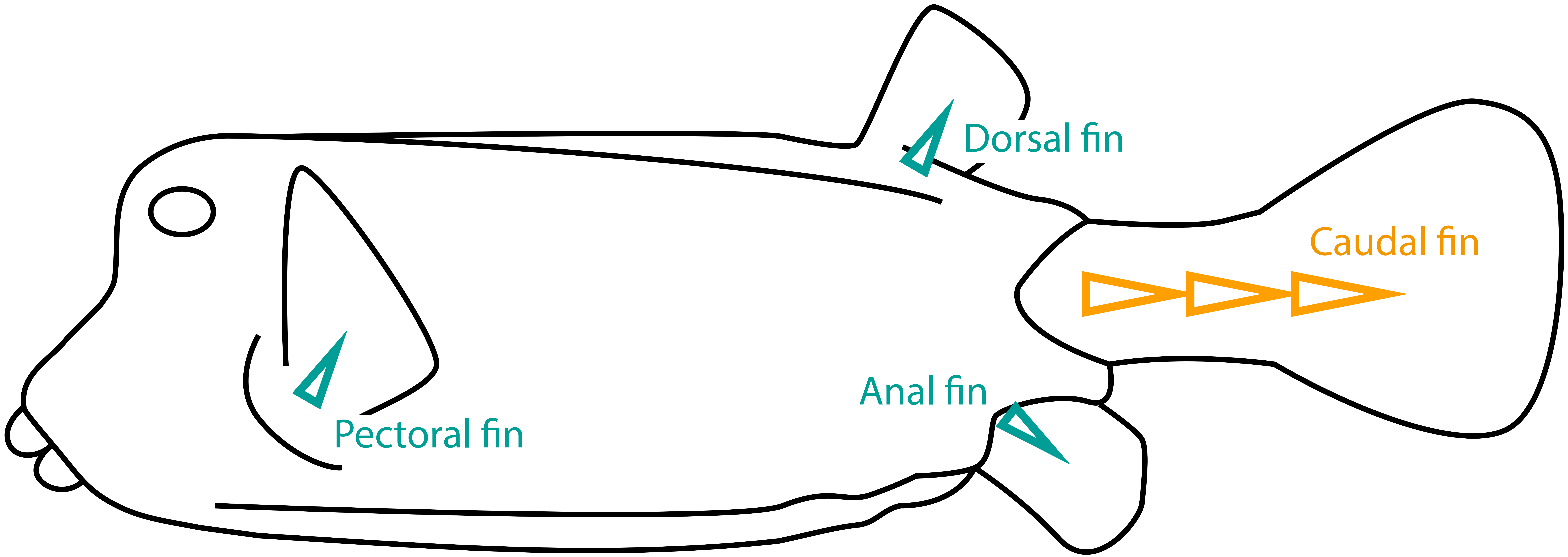
Example 1 - Labriform

- Mainly use body trunk - caudal fin and/or pectoral fin to swim



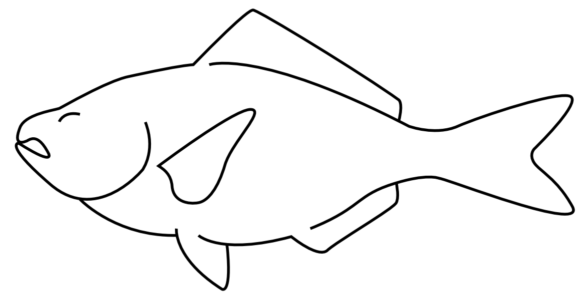
Example 2 - Ostraciiform

- Mainly use caudal fin, pectoral fin, dorsal fin, and/or anal fin to swim

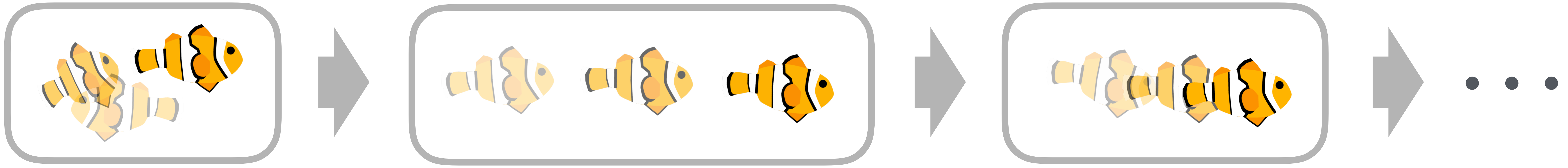


Categorize swimming motion in each Swimming mode

- Fish change how to move skeleton (Swimming form) with time



Labriform



Body trunk
  -> bend strongly

Pectoral fin
  -> do not move

...

C-Start

Body trunk
  -> undulate

Pectoral fin
  -> do not move

...

Subcarangiform

Body trunk
  -> do not move

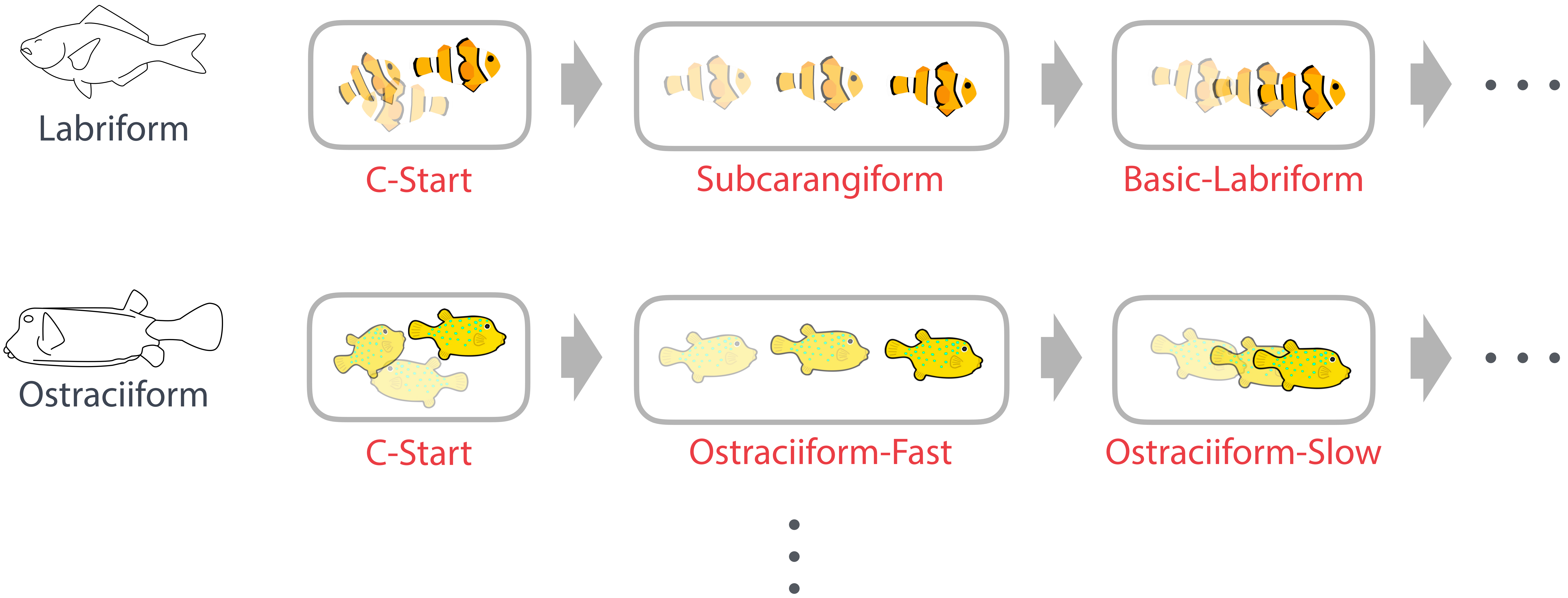
Pectoral fin
  -> oscillate

...

Basic-Labriform

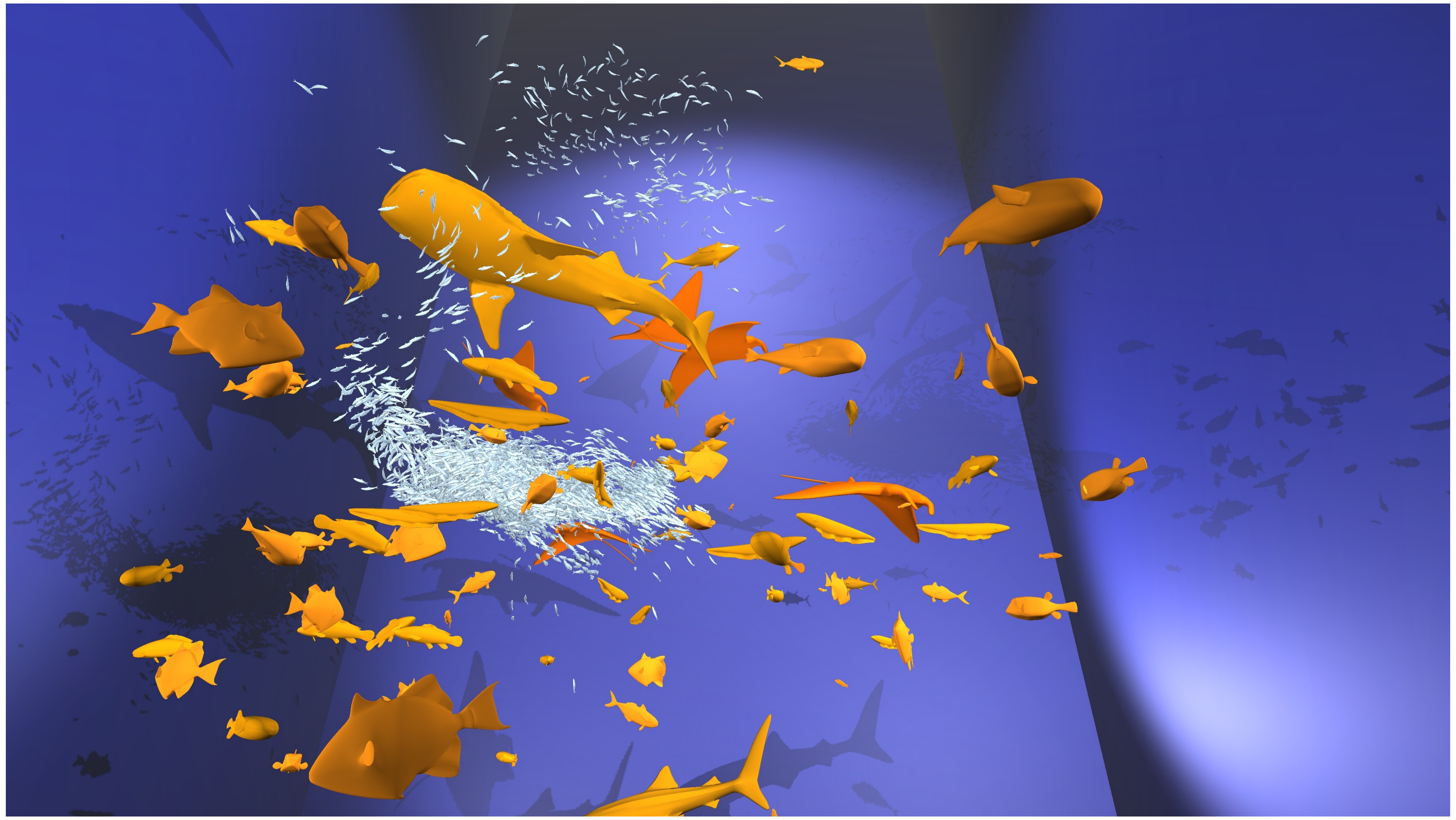
Categorize swimming motion in each Swimming mode

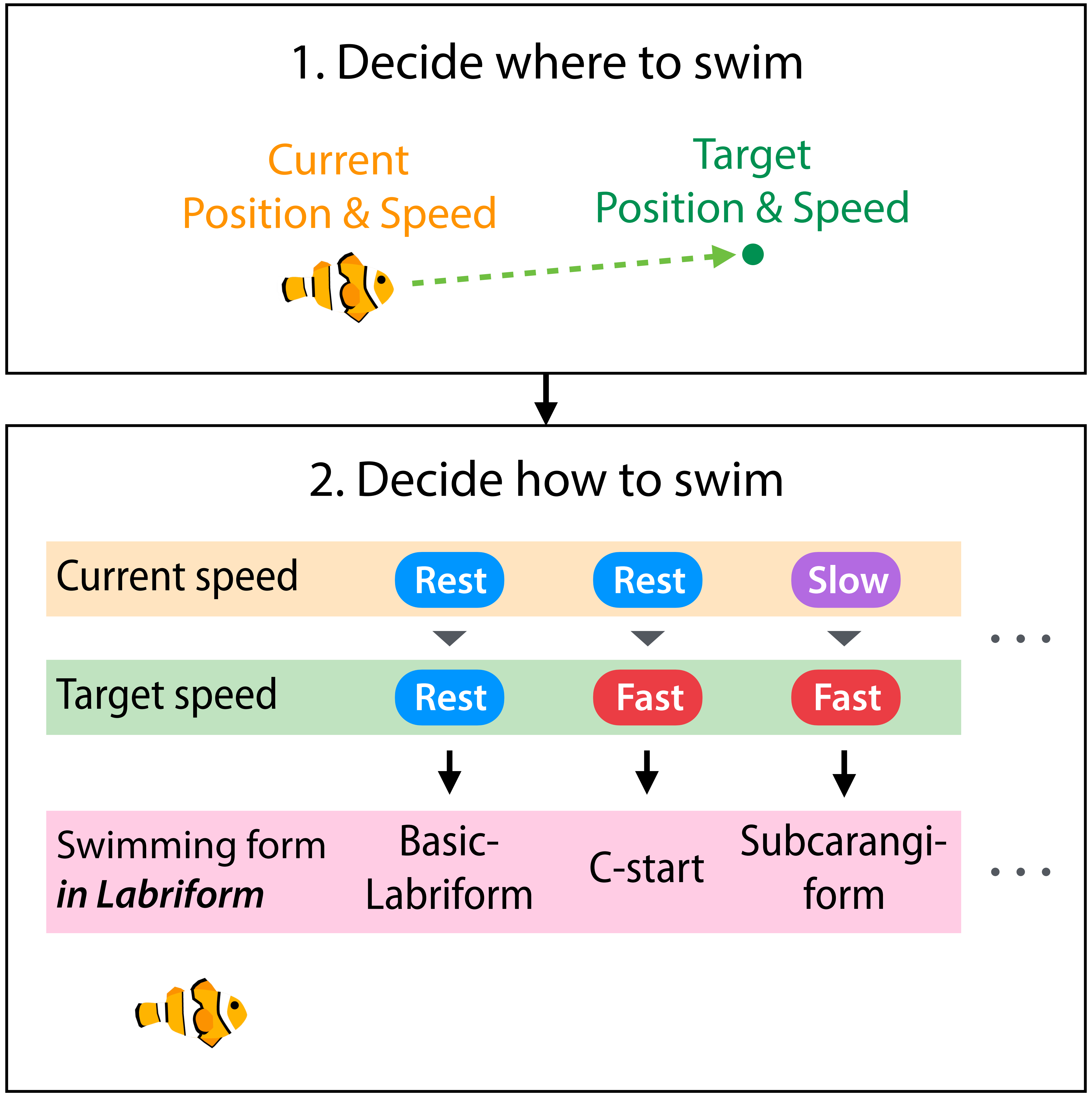
- Swimming form is common idea among 12 Swimming modes



Unified Motion Planner

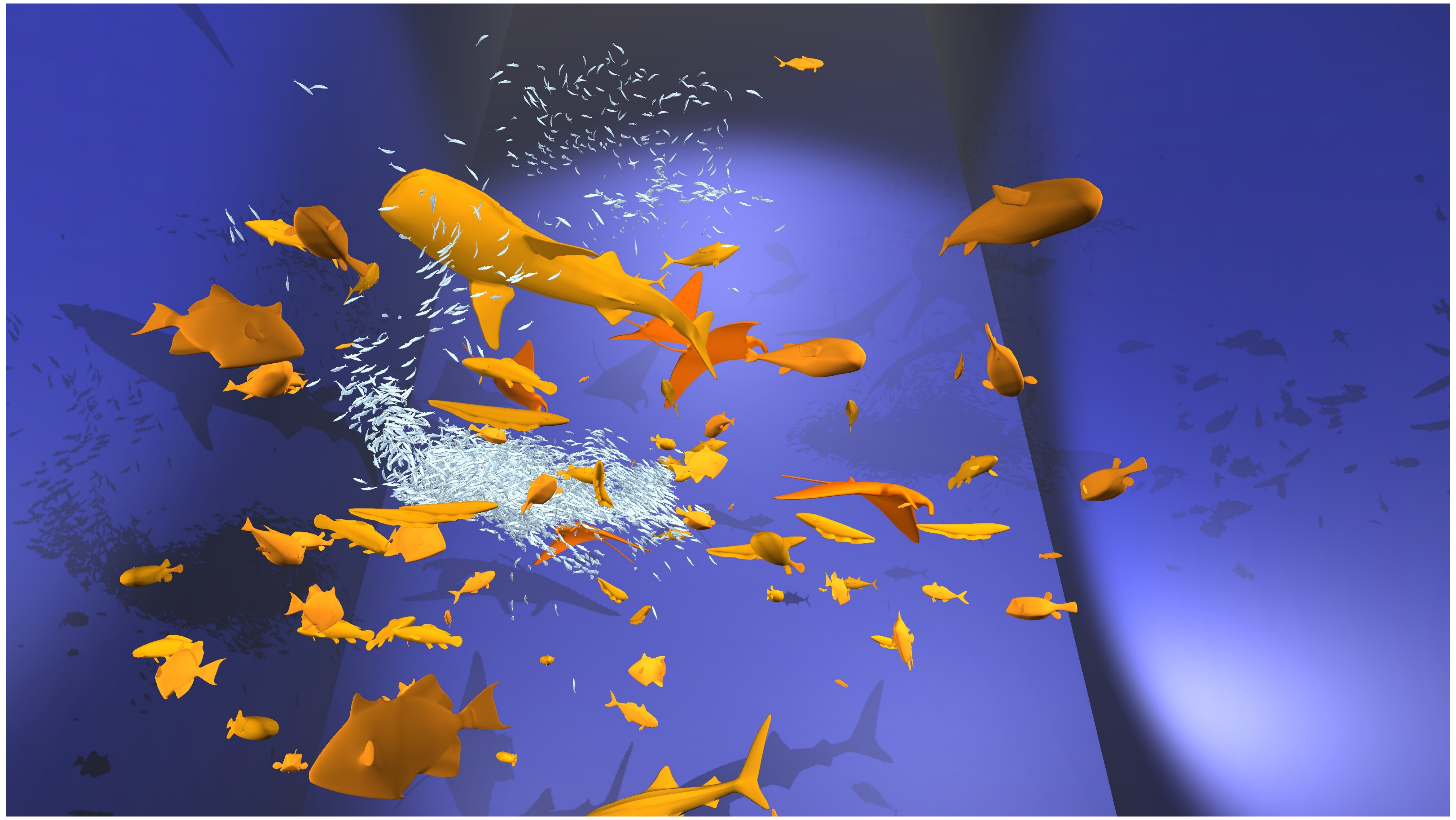
- Use two-stage decision making process to reproduce various swimming styles
  - 1. Decide where to swim - Target position & speed
  - 2. Decide how to swim - Swimming form

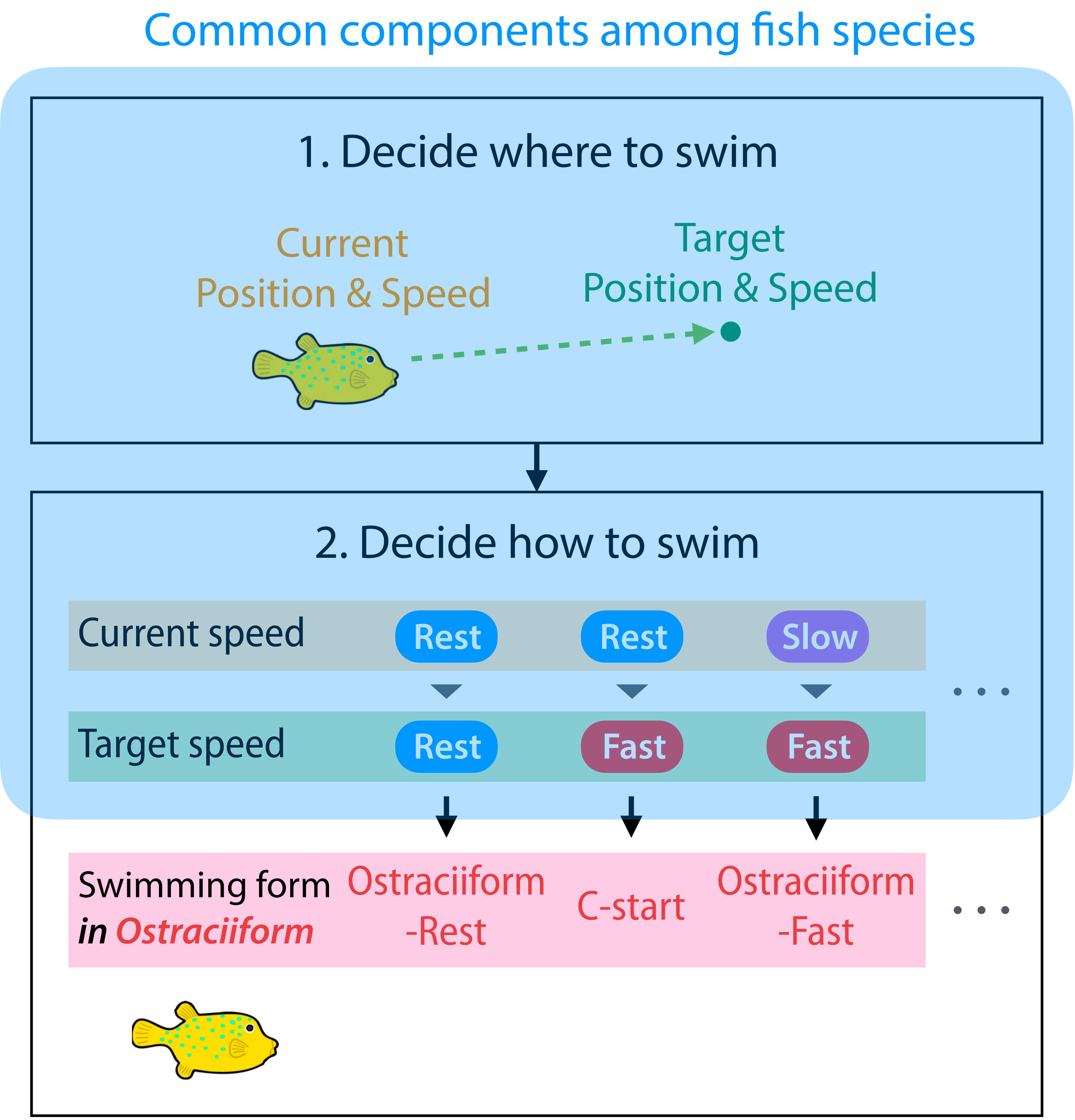




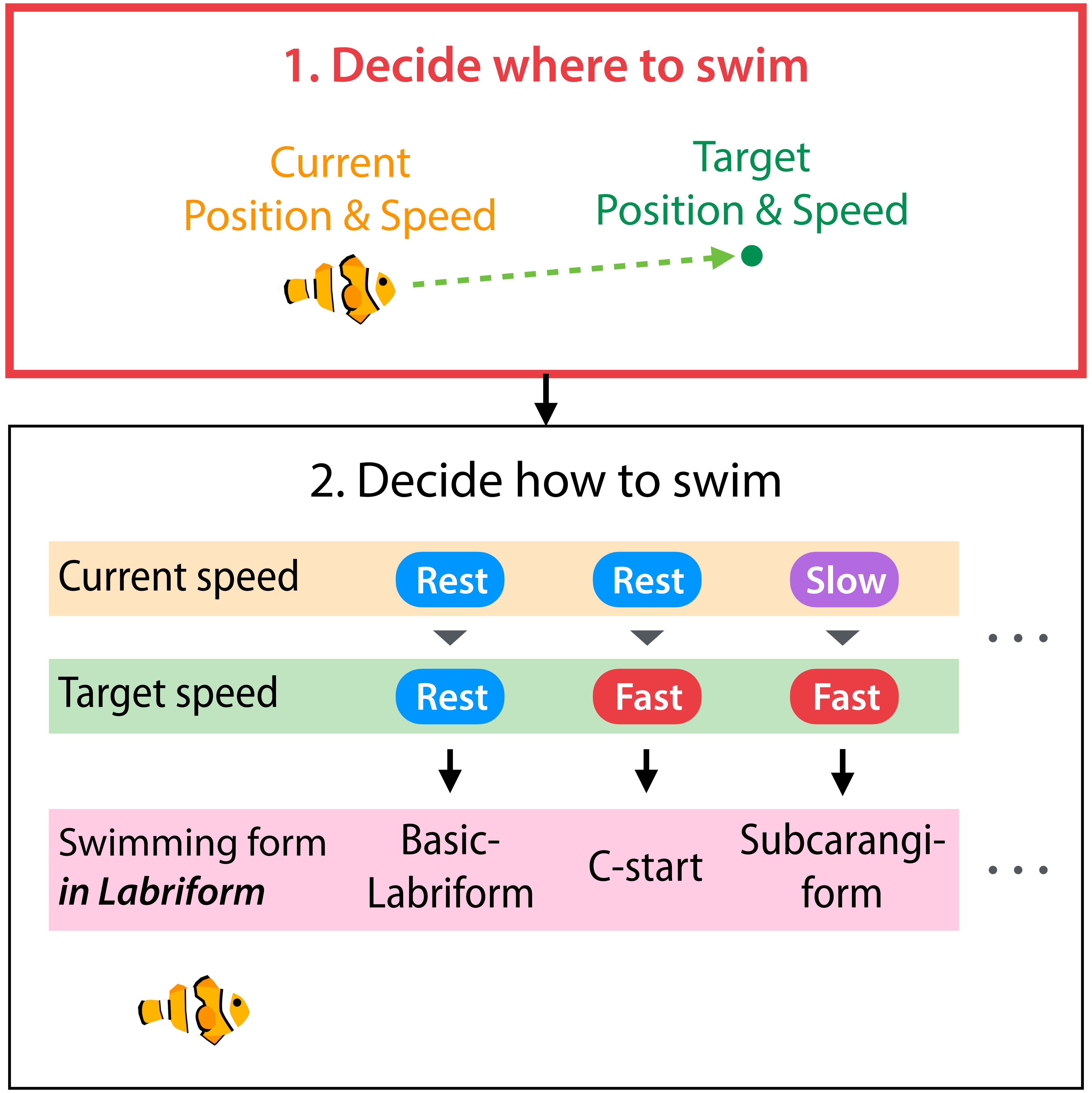
Unified Motion Planner

- How to reproduce motion of other fish species?
  -> replace Swimming forms



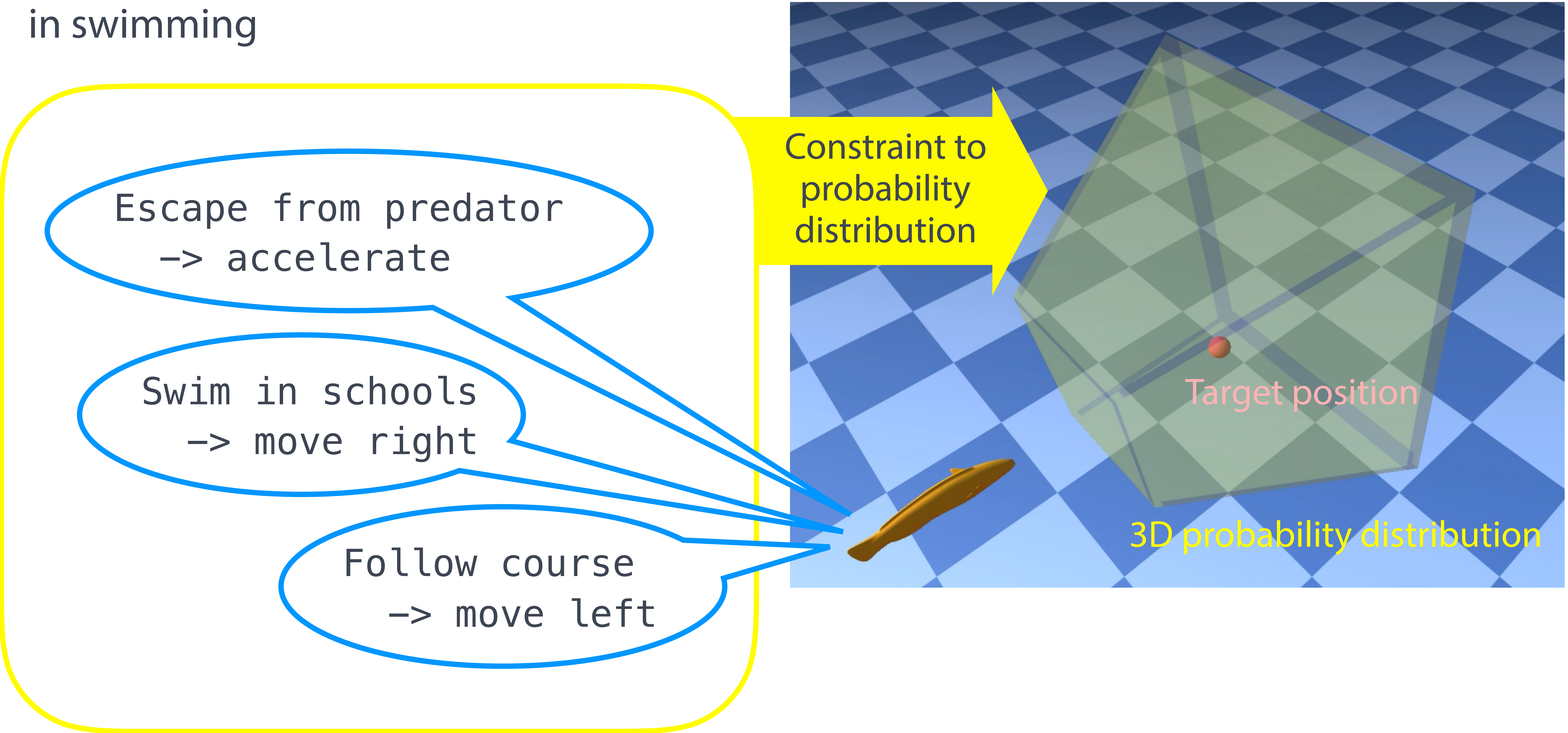


Target selection & Locomotion control

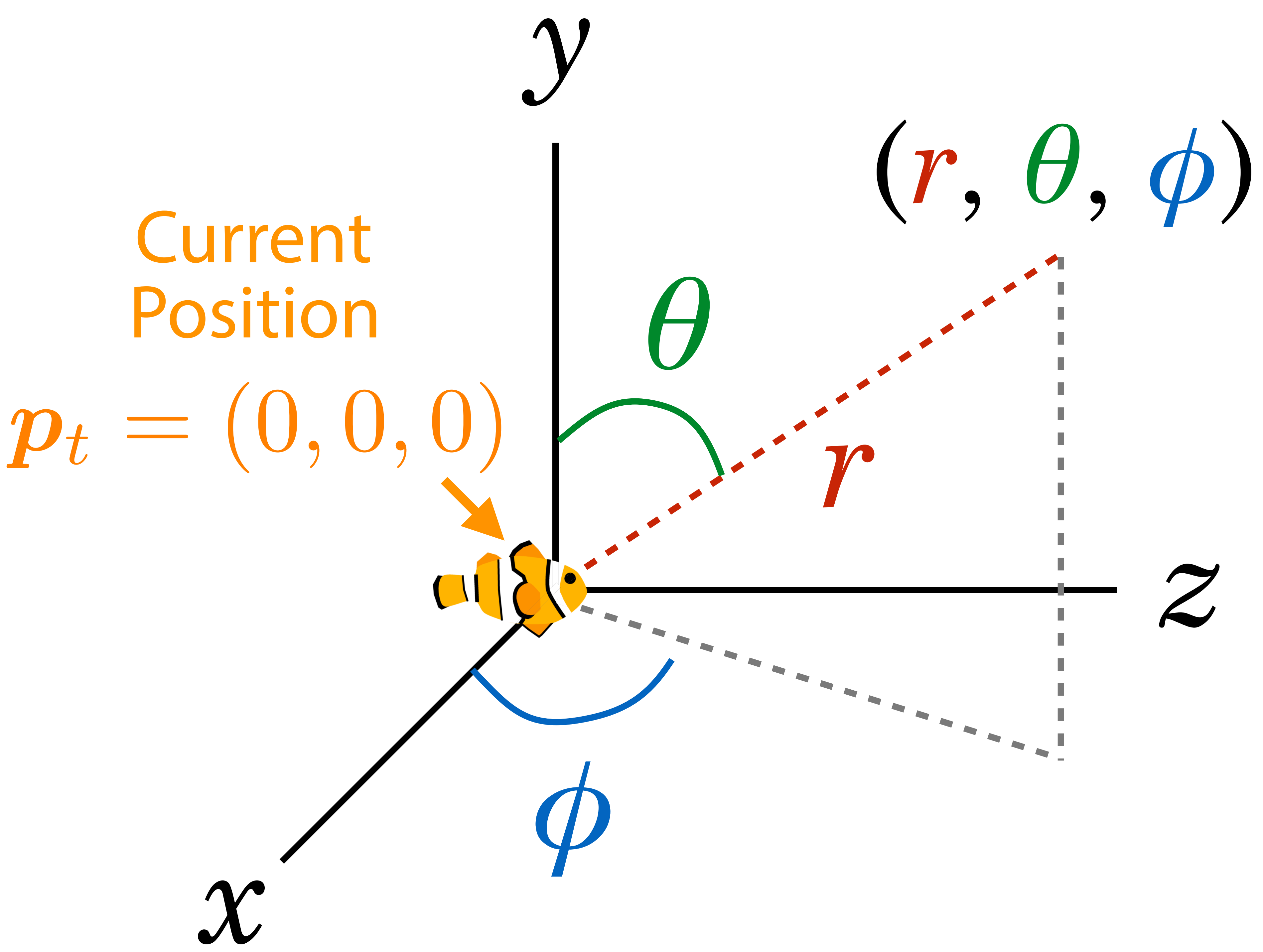


Basic concept of target selection

- Balance a number of factor in swimming

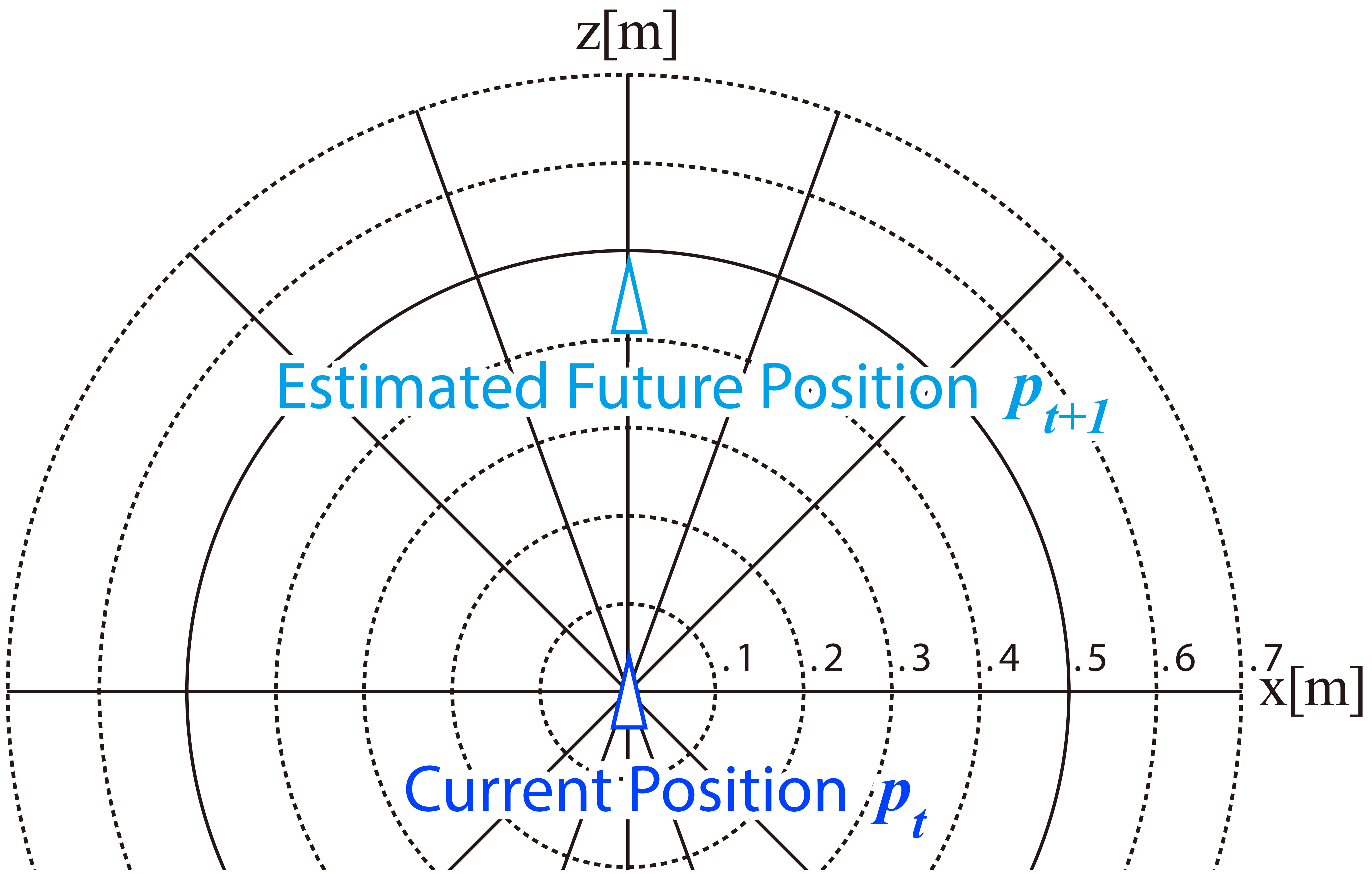


Local spherical coordinate



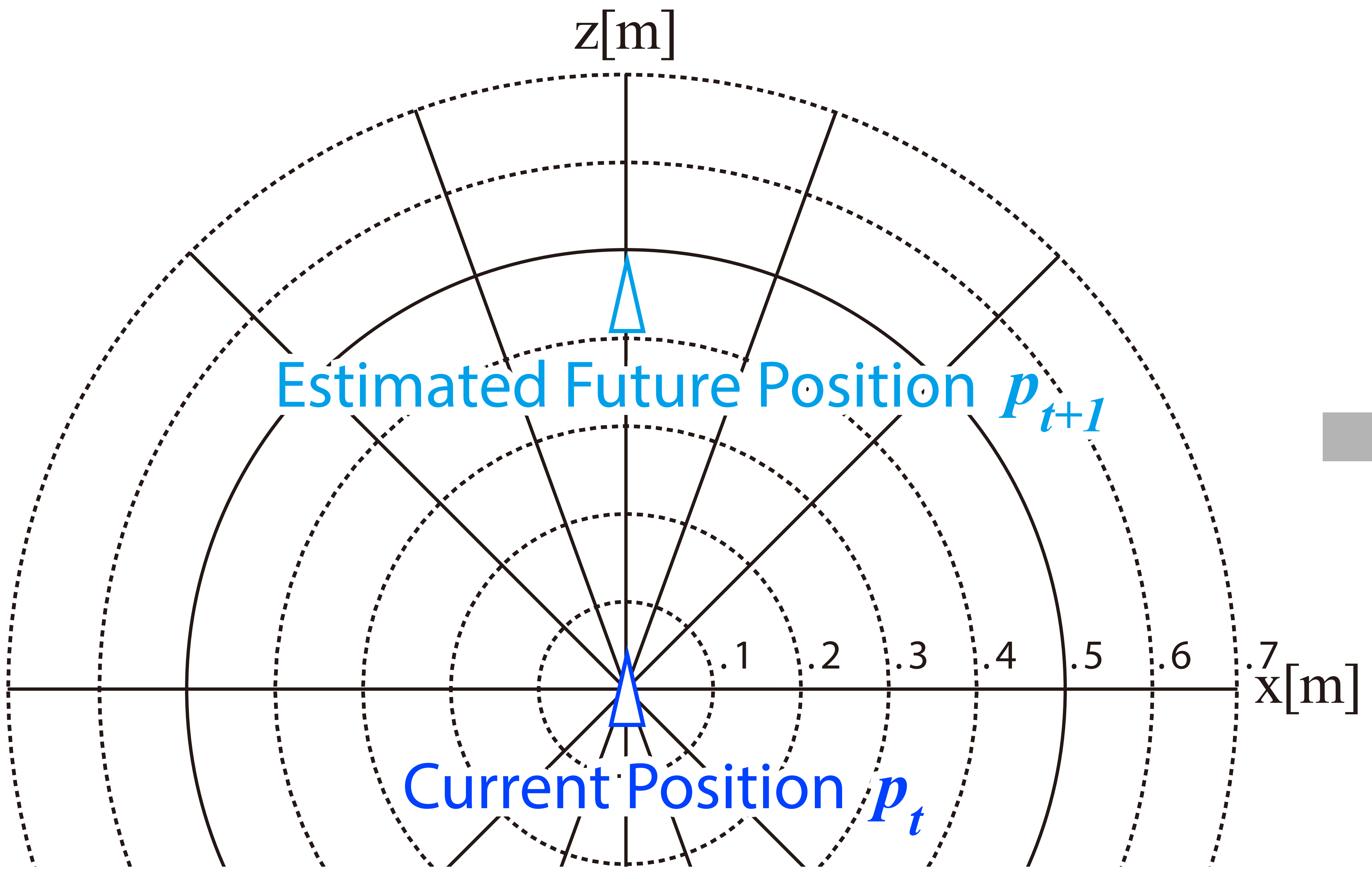
Target selection (1/6) - Estimate future position

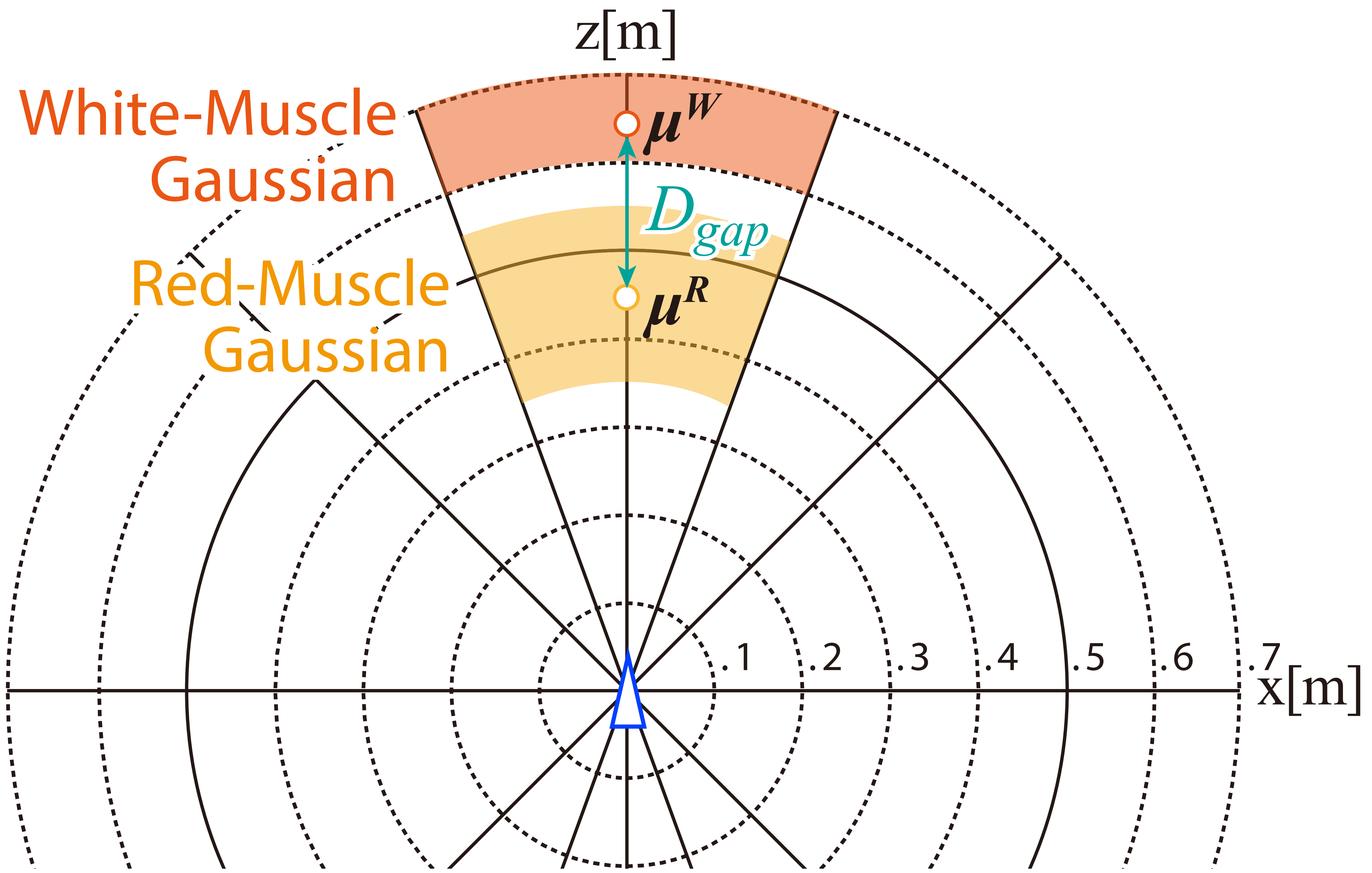
- p_{t+1}: the position that will be reached
  if the present transitional & angular speed is maintained throughout in next MU



Target selection (2/6) - Initialize probability distributions

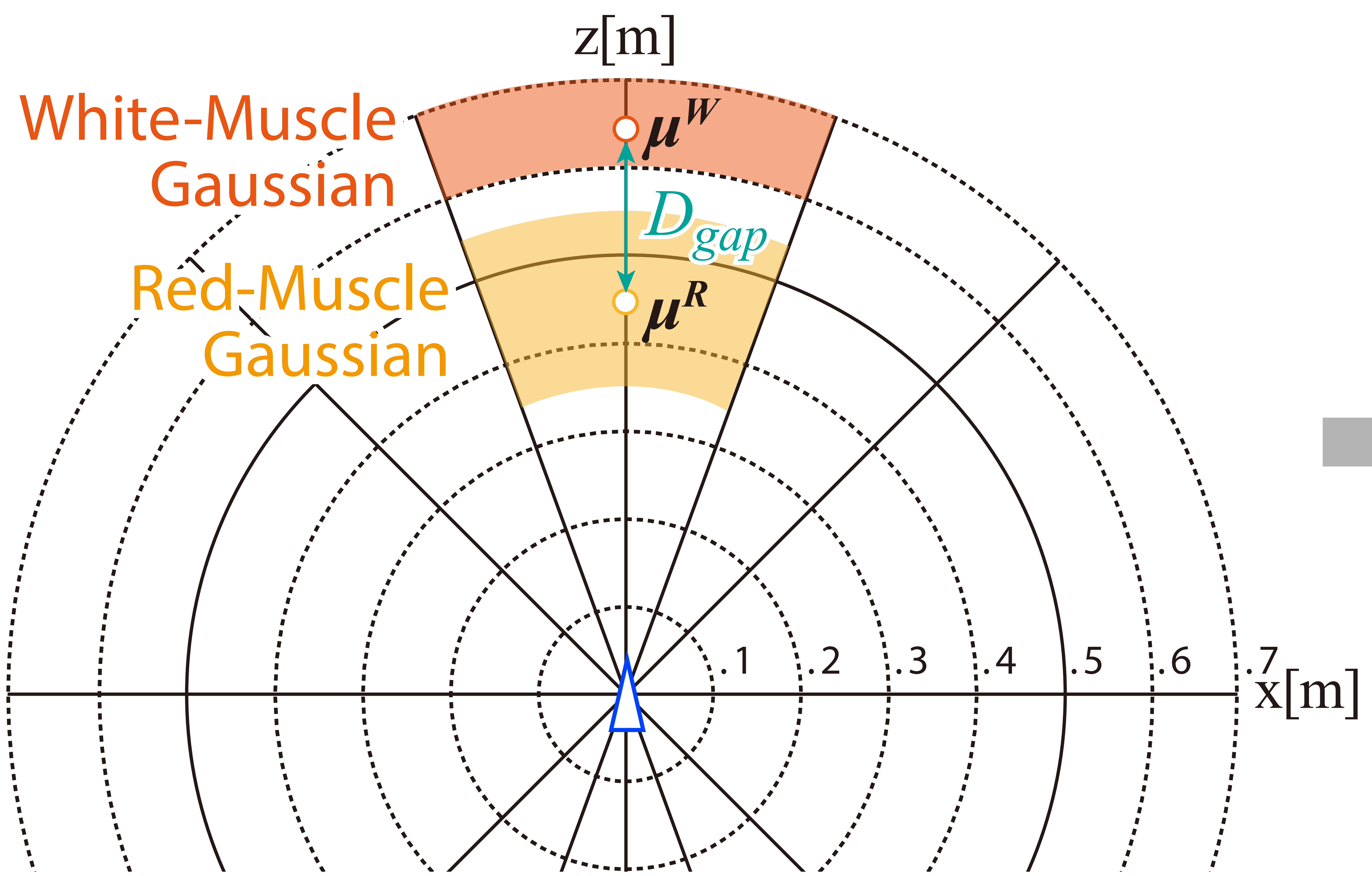
- Generate 3D gaussian distribution around p_{t+1}
- Two gaussians: using white muscle or red muscle

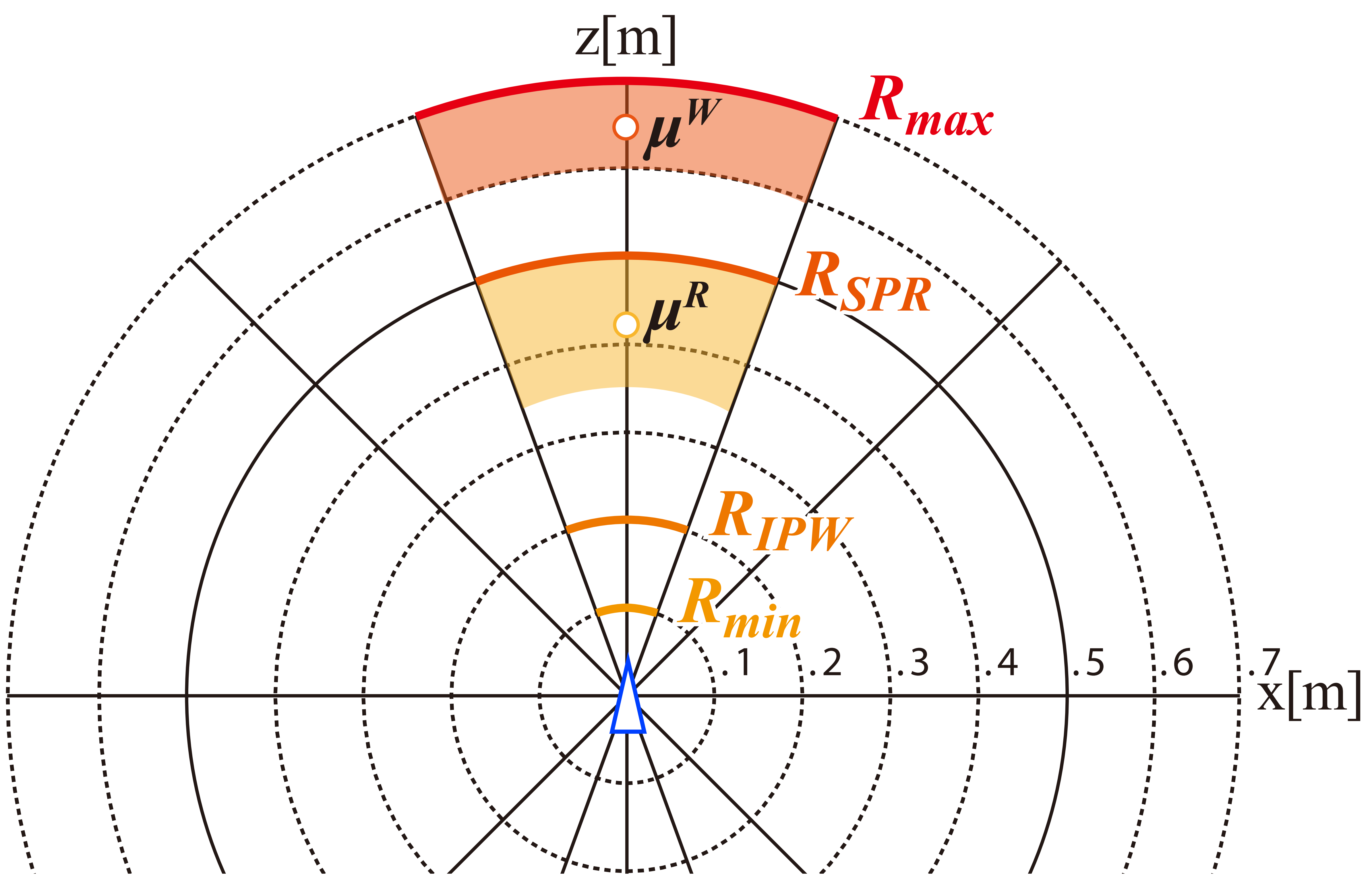




Target selection (3/6) - Constraint by speed characteristics

- R_{max} : the maximum possible speed of a fish species
- R_{SPR} : the maximum speed at which red muscles are the main muscles used
- R_{IPW} : the speed at which the white muscles start to become active
- R_{min} : the minimum speed required for swimming



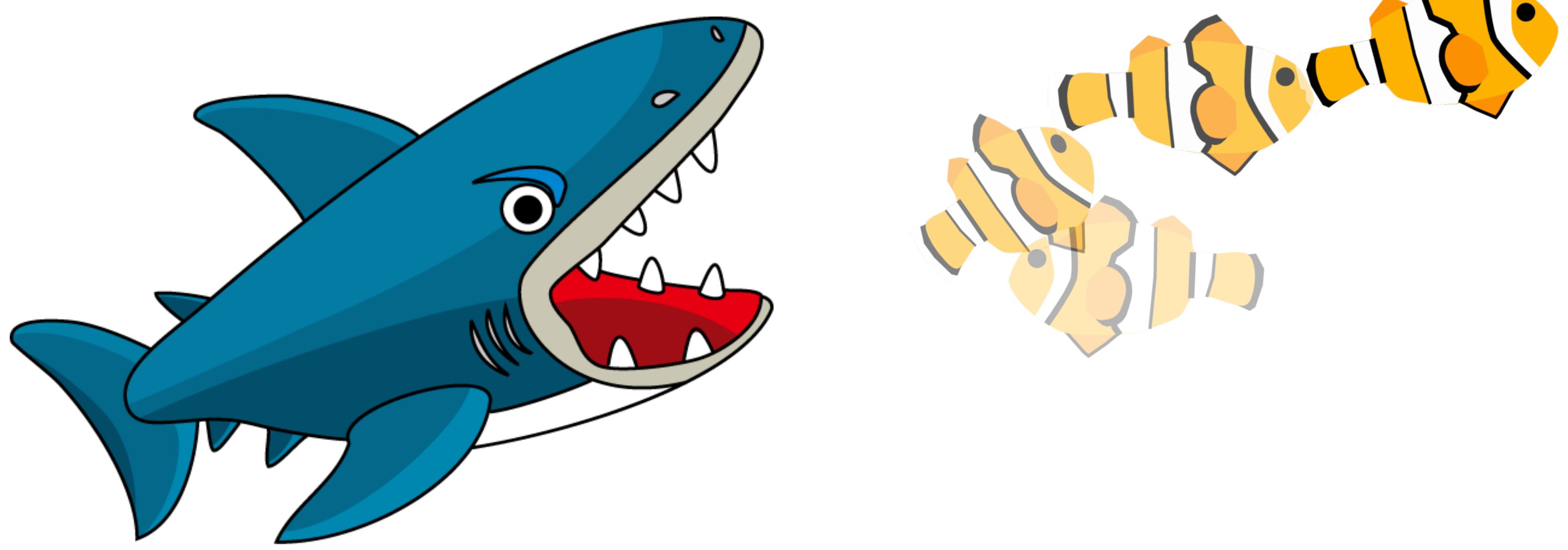


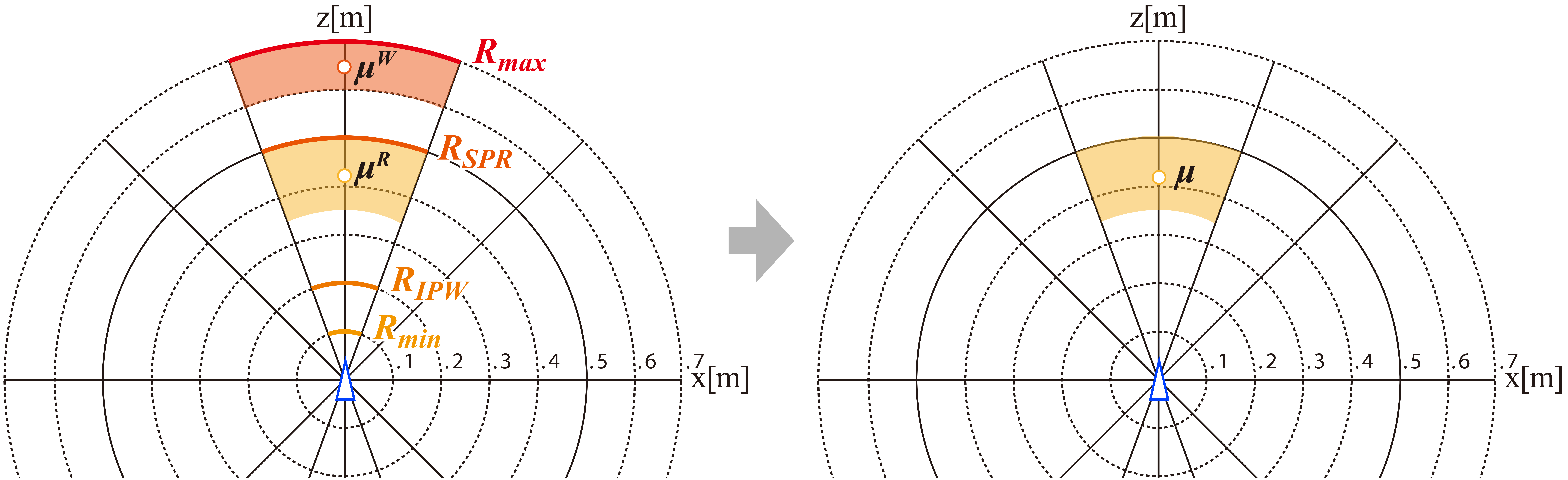
Target selection (4/6) - Constraint by behavior routines

- Fish select *"free swimming"*, *"avoid"* or *"escape"* behavior
- In this example:

  "free swimming" is selected -> use red muscle

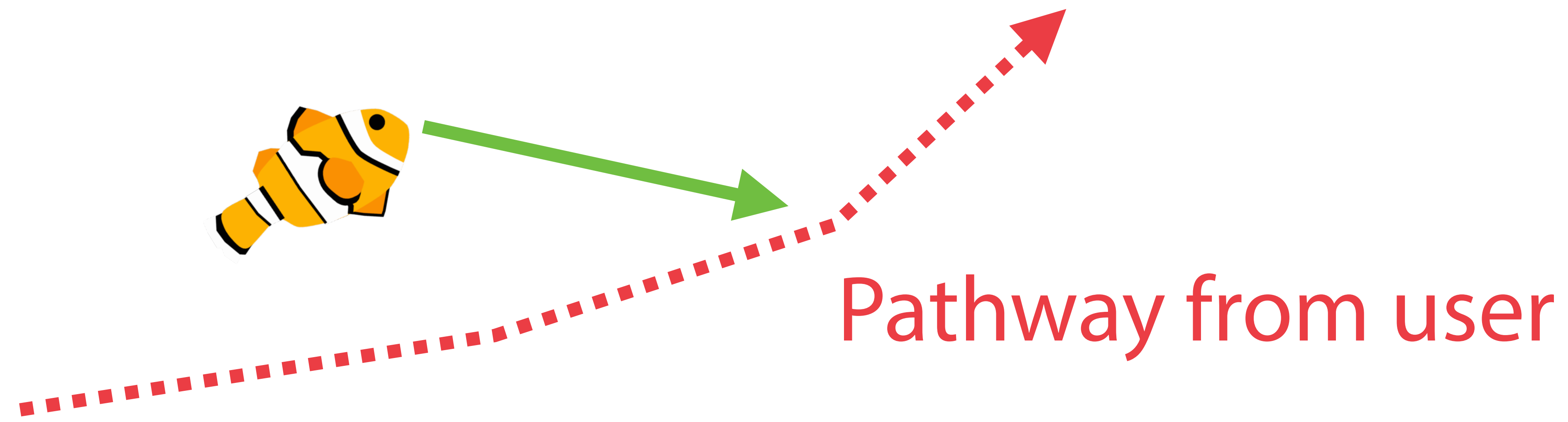
  -> delete White-Muscle Gaussian

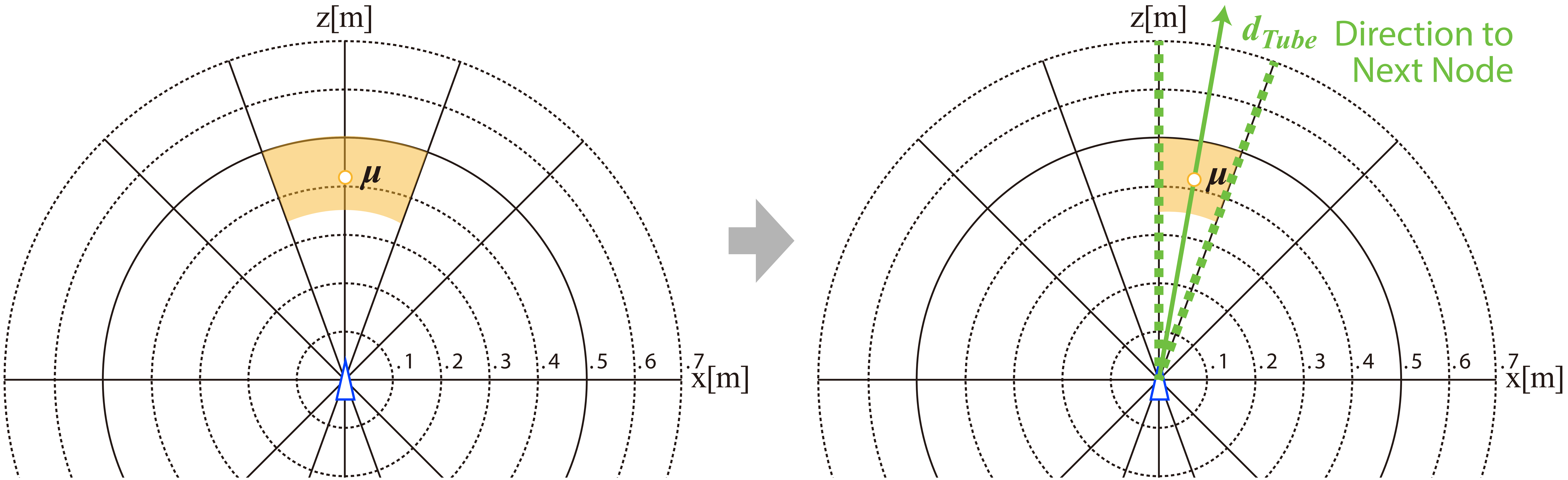




Target selection (5/6) - Constraint by path-following

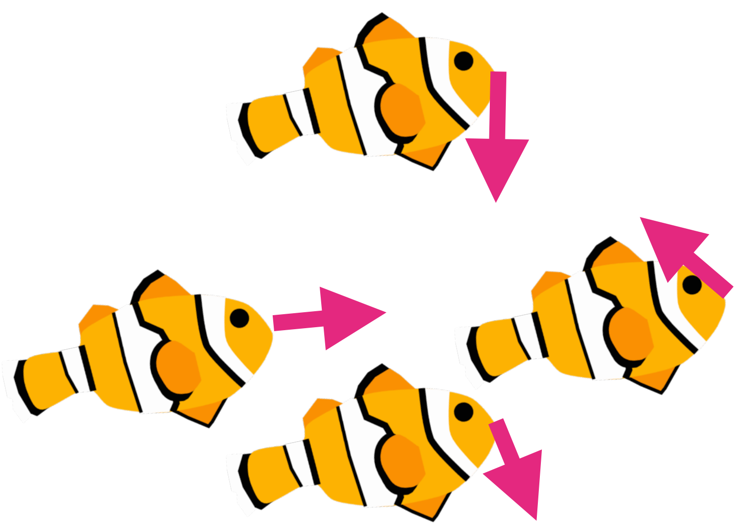
- Probability distribution is clipped to within the set angle from d_{Tube}

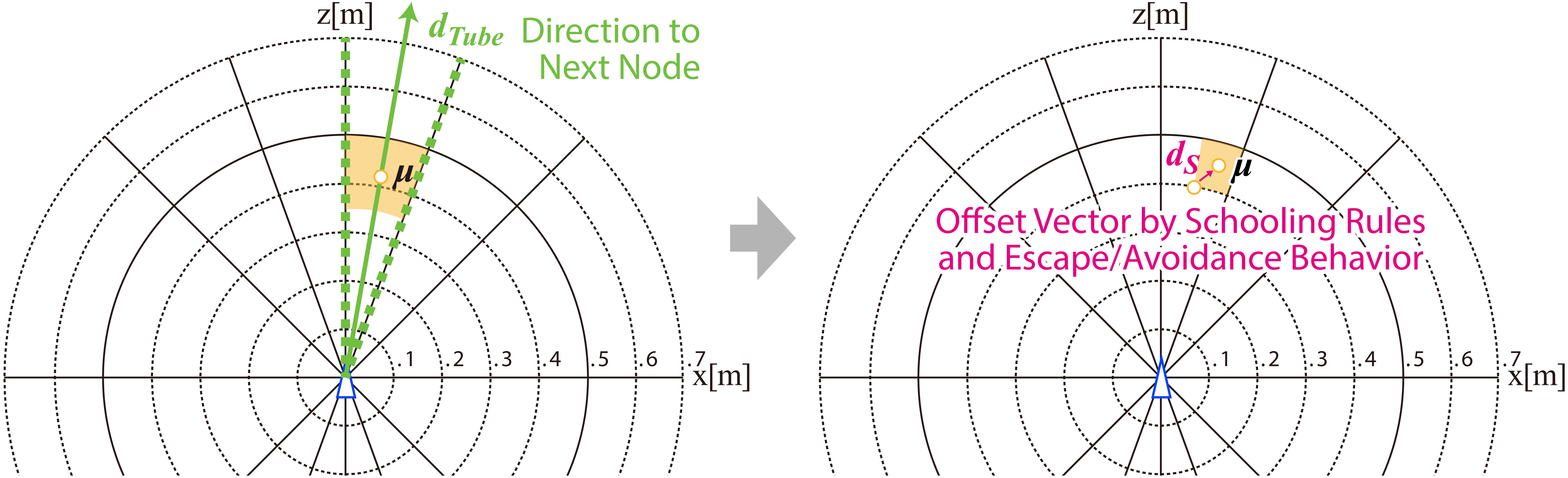




Target selection (6/6) - Constraint by schooling behavior

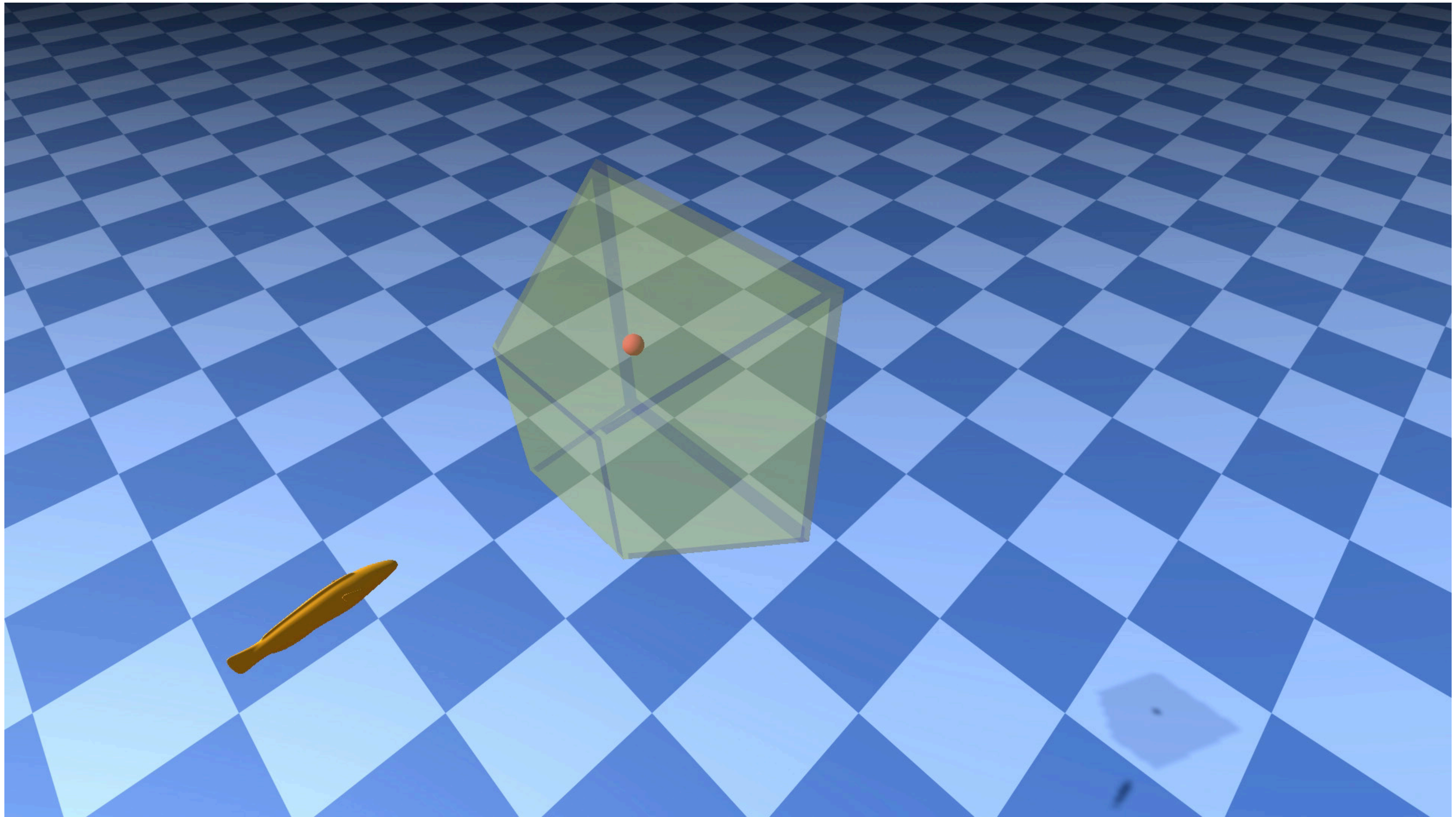
- Shift the mean μ using offset vector d_S by schooling behavior
- Use Boids algorithm *[Reynolds 1987]* to calculate d_S



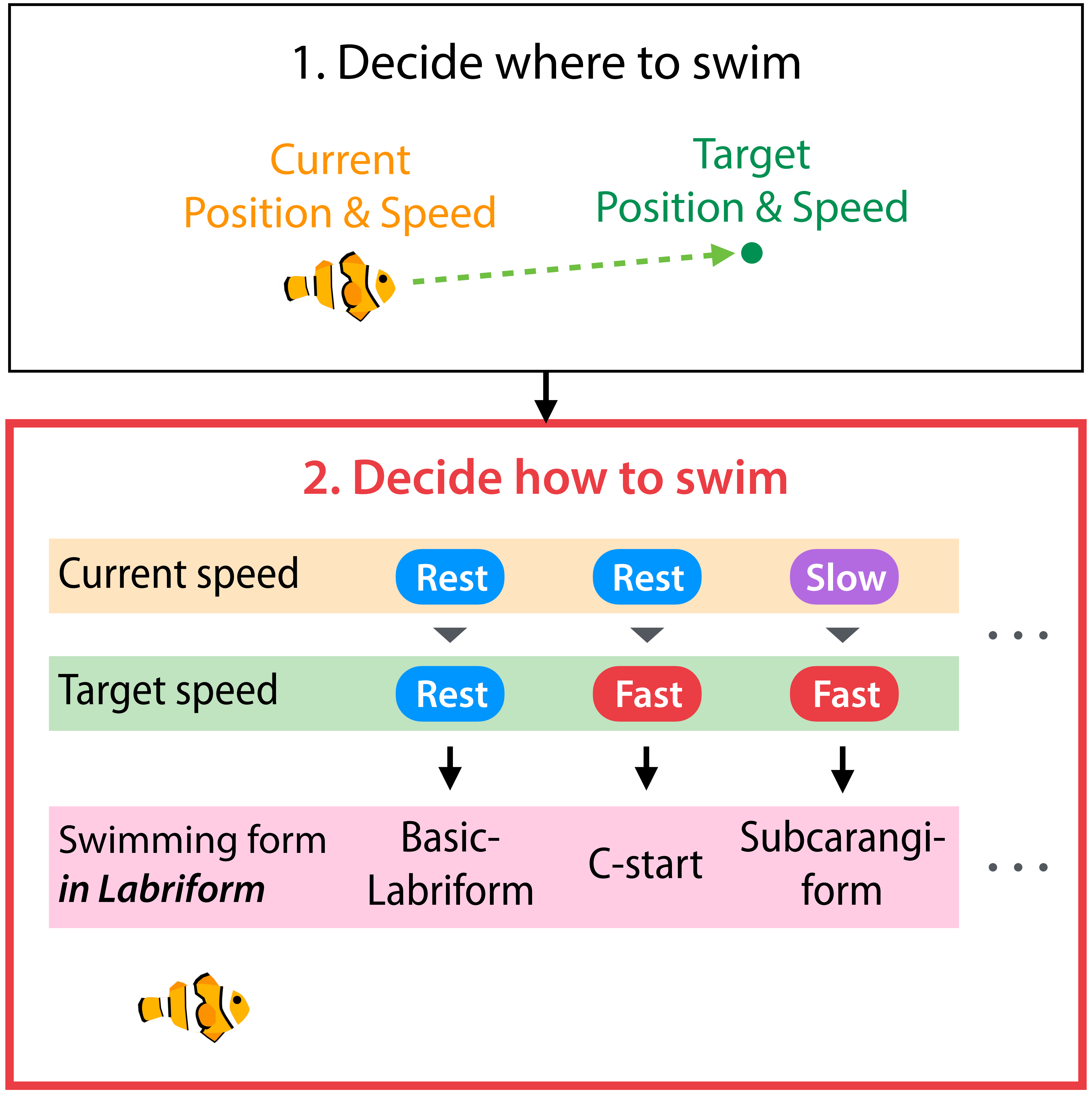


Locomotion control

- Fish always head for target position
  - acceleration -> uniformly-accelerated motion
  - angular acceleration -> turn toward target using PID control



Swimming form selection & Skeleton control



Basic concept of Swimming form selection

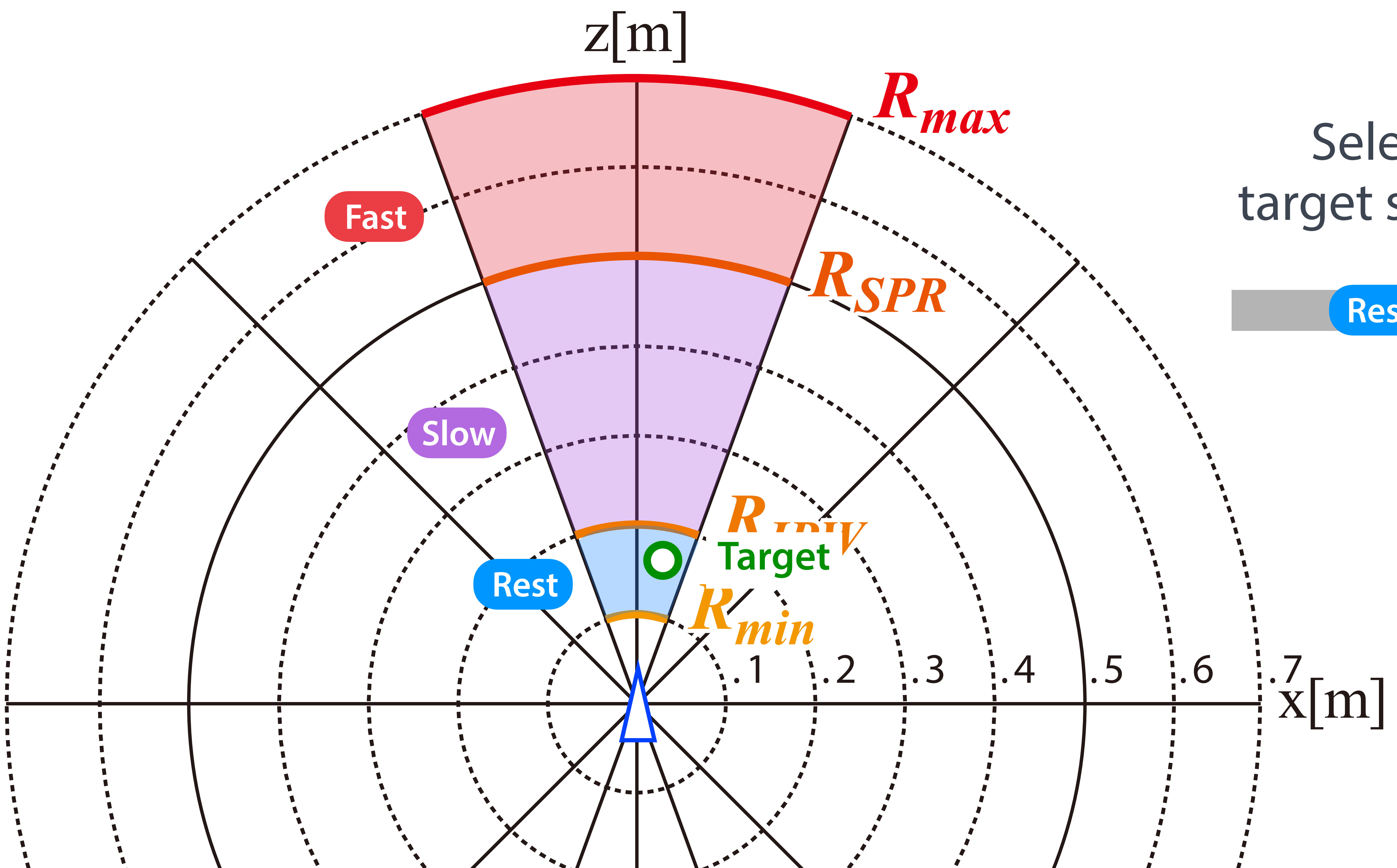
- Based on the transition of qualitative speed
  - 3x3 = 9 combinations
  - Partially adopted knowledges in fish physiology *[Archer and Johnston 1989; Walker 2000; Hove+ 2001]*

Current speed	Rest	Rest	Rest	Slow	Slow	Slow	Fast	Fast	Fast
Target speed	Rest	Slow	Fast	Rest	Slow	Fast	Rest	Slow	Fast
Swimming form ***in Labriform***	Basic-Labriform	C-start	Subcarangi-form	Basic-Labriform	Basic-Labfiform	Subcarangi-form	Basic-Labriform	Basic-Labfiform	Subcarangi-form

Estimate target speed

- Select Rest, Slow, or Fast by using r'_{t+1}
  r'_{t+1} : r component of target position

$$U_{Q_{t+1}} = \begin{cases} \text{[Rest]} & \text{if} \quad R_{min} \leq r'_{t+1} < R_{IPW} \\ \text{[Slow]} & \text{if} \quad R_{IPW} \leq r'_{t+1} < R_{SPR} \\ \text{[Fast]} & \text{if} \quad R_{SPR} \leq r'_{t+1} \leq R_{max} \end{cases}$$



Select target speed

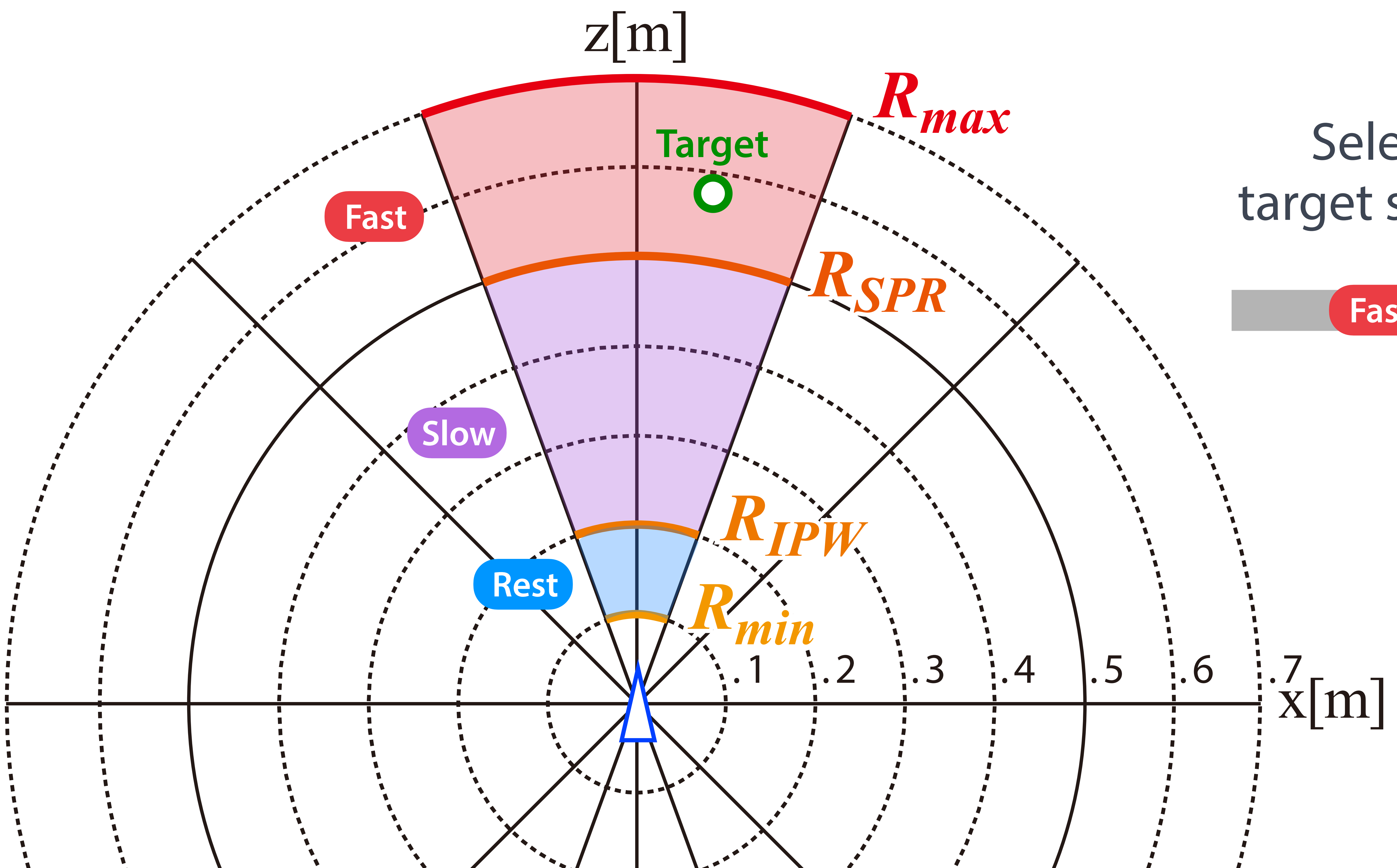
Rest

Current speed	Rest
Target speed	Rest
Swimming form *in Labriform*	Basic-Labriform

Estimate target speed

- Select Rest , Slow , or Fast by using r'_{t+1}
  r'_{t+1} : r component of target position

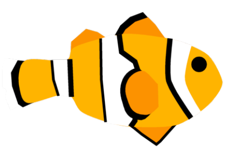
$$U_{Q_{t+1}} = \begin{cases} [\text{Rest}] & \text{if} \quad R_{min} \leq r'_{t+1} < R_{IPW} \\ [\text{Slow}] & \text{if} \quad R_{IPW} \leq r'_{t+1} < R_{SPR} \\ [\text{Fast}] & \text{if} \quad R_{SPR} \leq r'_{t+1} \leq R_{max} \end{cases}$$



Select
target speed

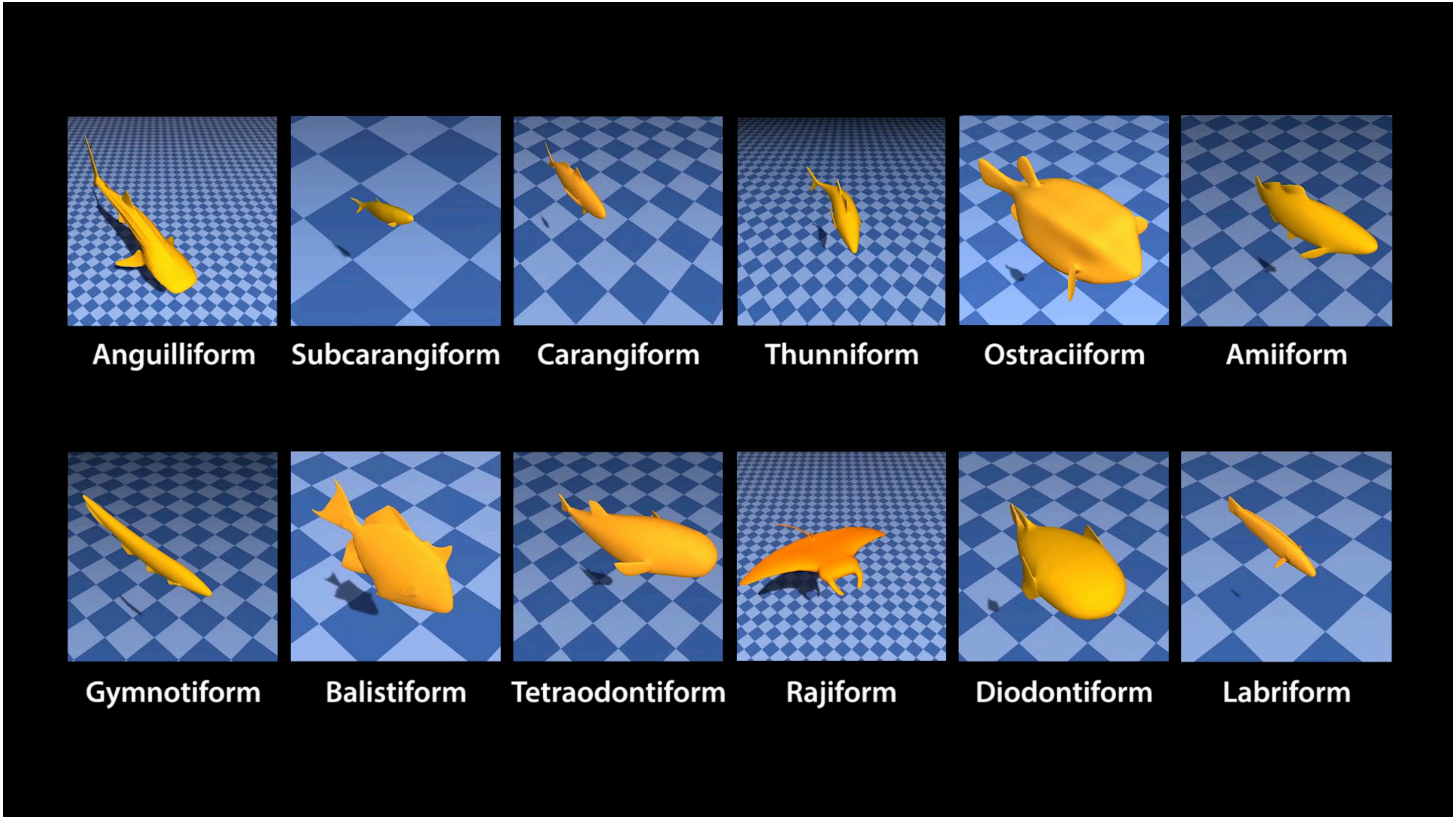
Fast

Current speed	Rest
Target speed	Fast
Swimming form *in Labriform*	C-start

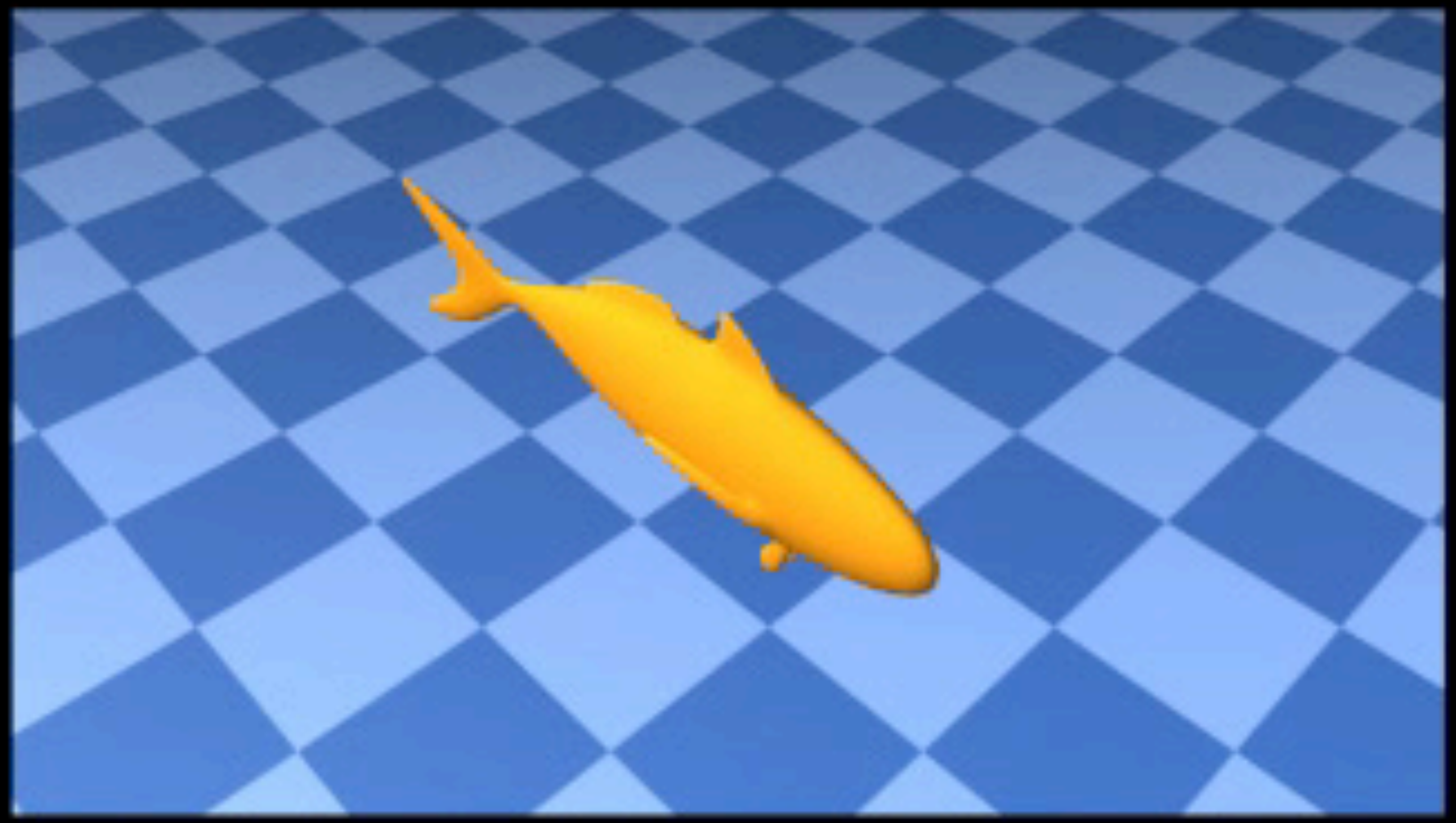


Results - Switch swimming form

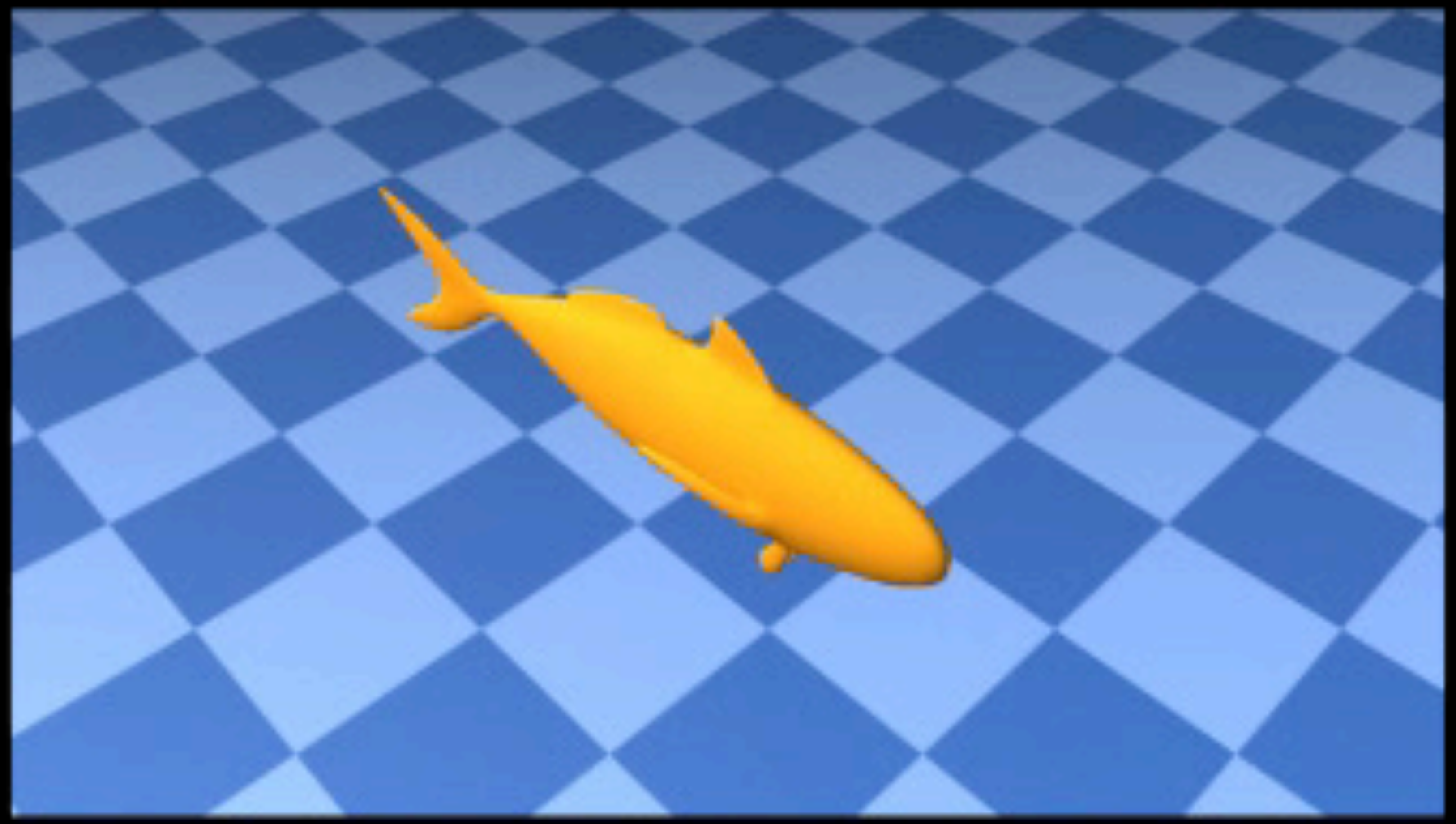
Results - 12 Swimming modes comparison



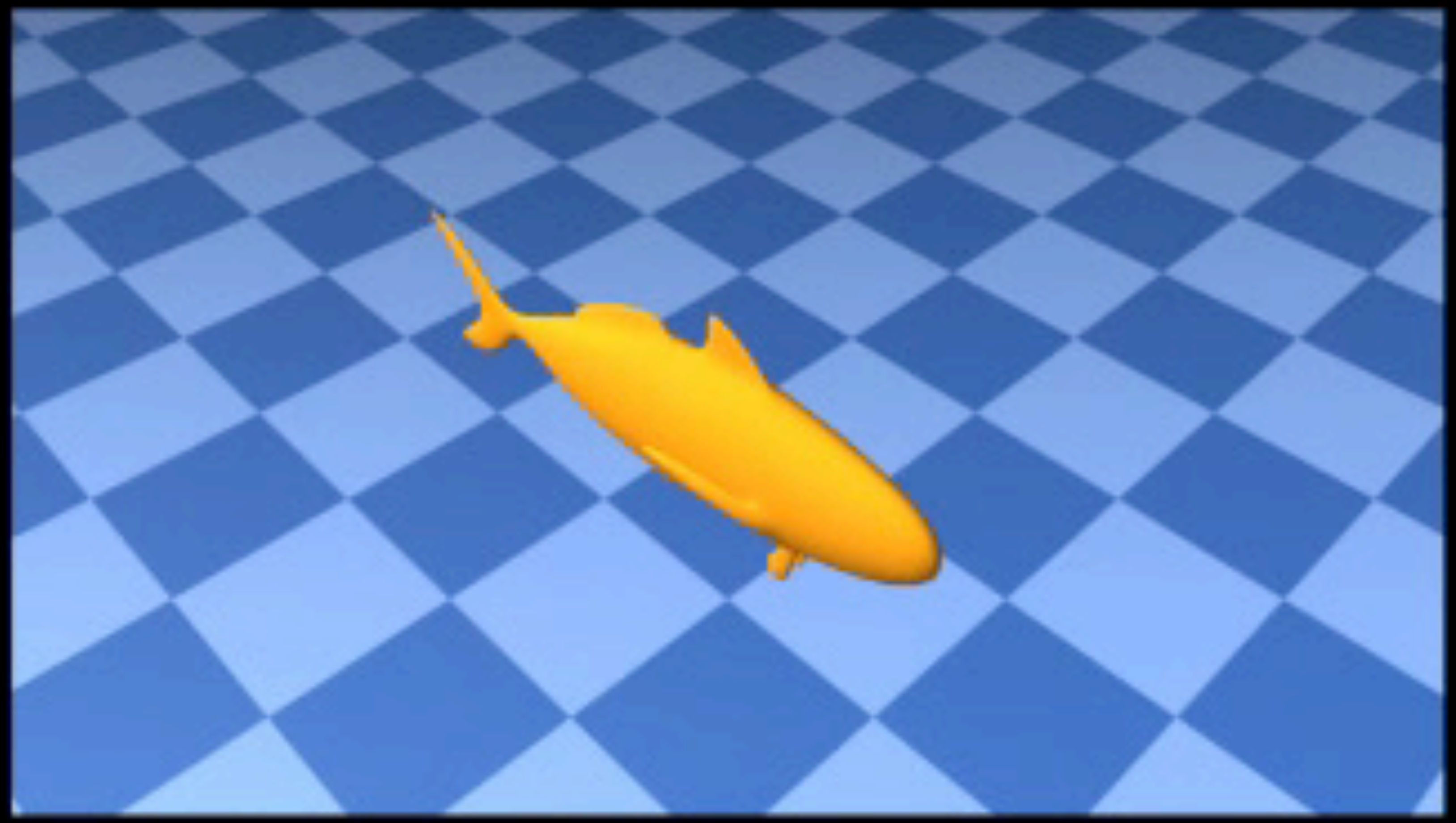
Results - Motion parameters comparison



$$T_{MU} = 0.06$$
$$U_{max} = 0.8$$
$$U_{SPR} = 0.25$$
$$U_{min} = 0.03$$



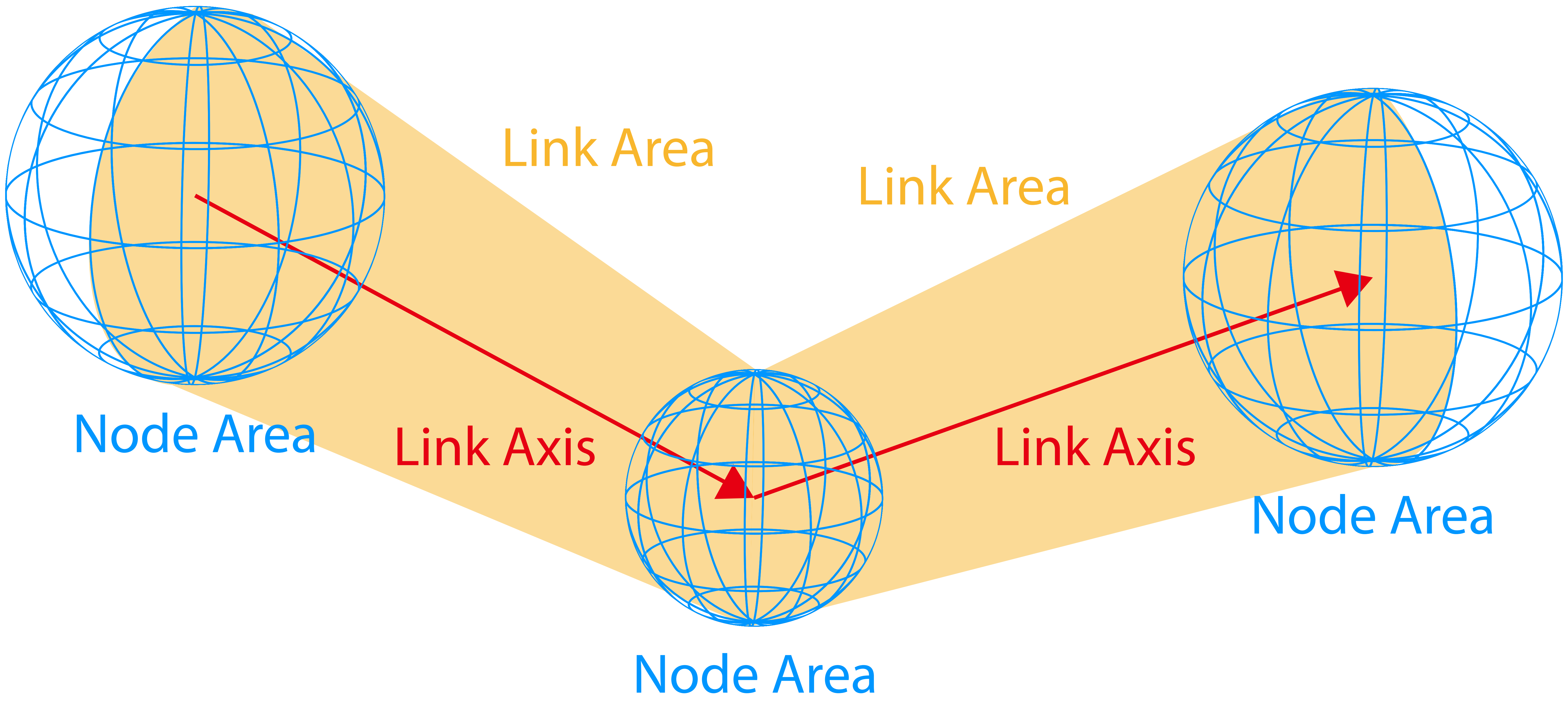
$$T_{MU} = 0.1$$
$$U_{max} = 3$$
$$U_{SPR} = 1$$
$$U_{min} = 0.075$$



$$T_{MU} = 0.5$$
$$U_{max} = 6$$
$$U_{SPR} = 2$$
$$U_{min} = 0.15$$

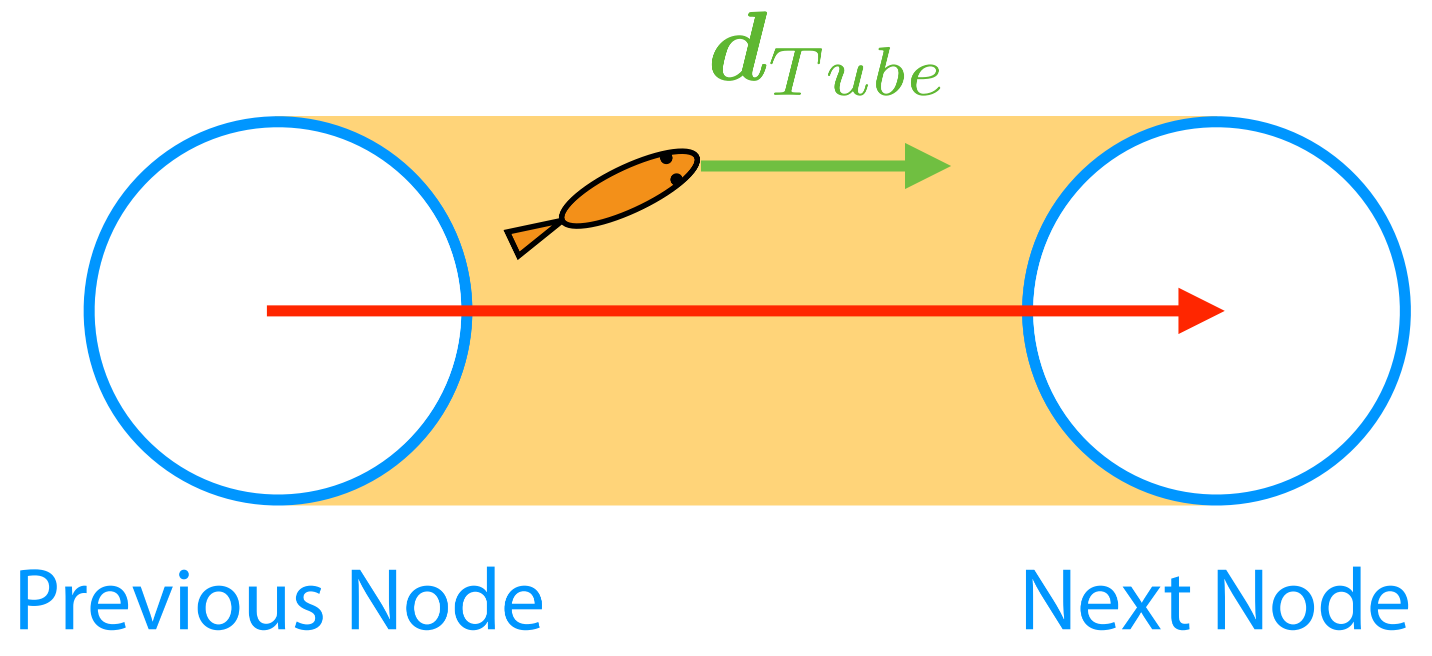
Tube-following

- Basic concept: represent fish school as “flow”

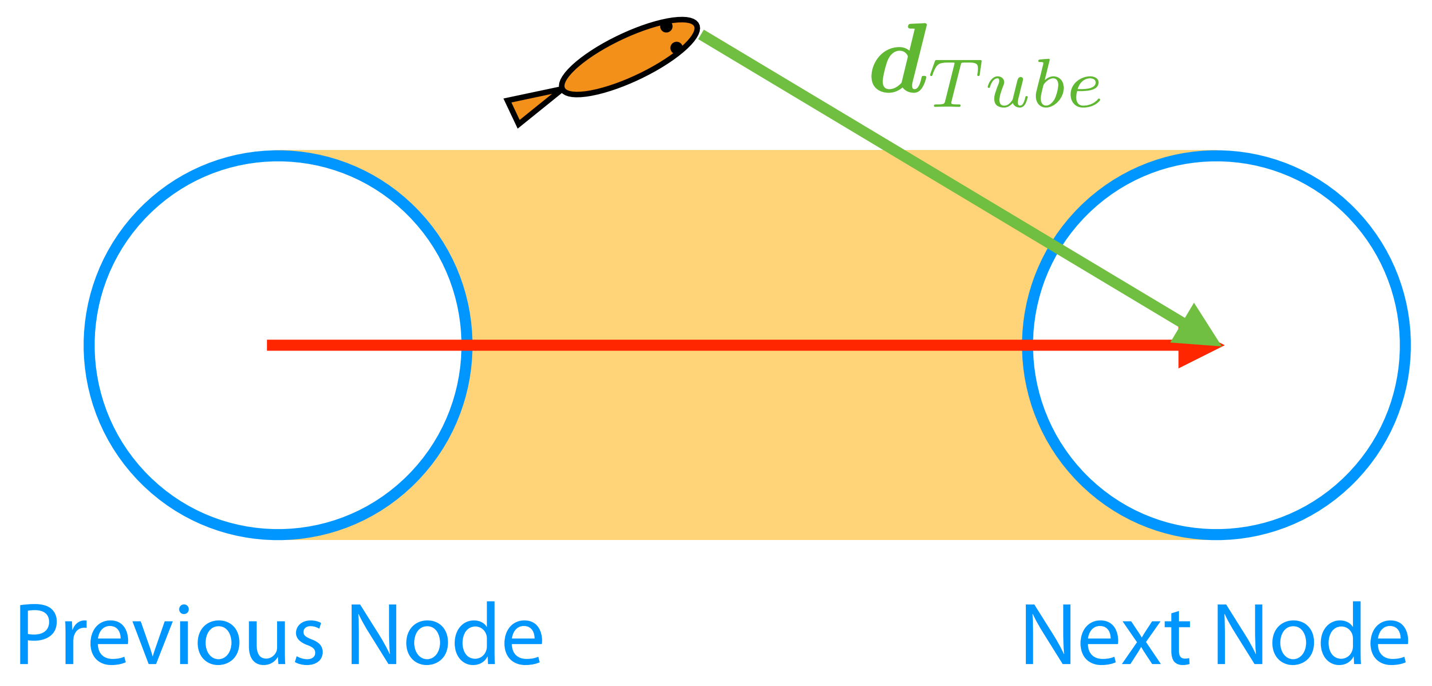


Tube-following

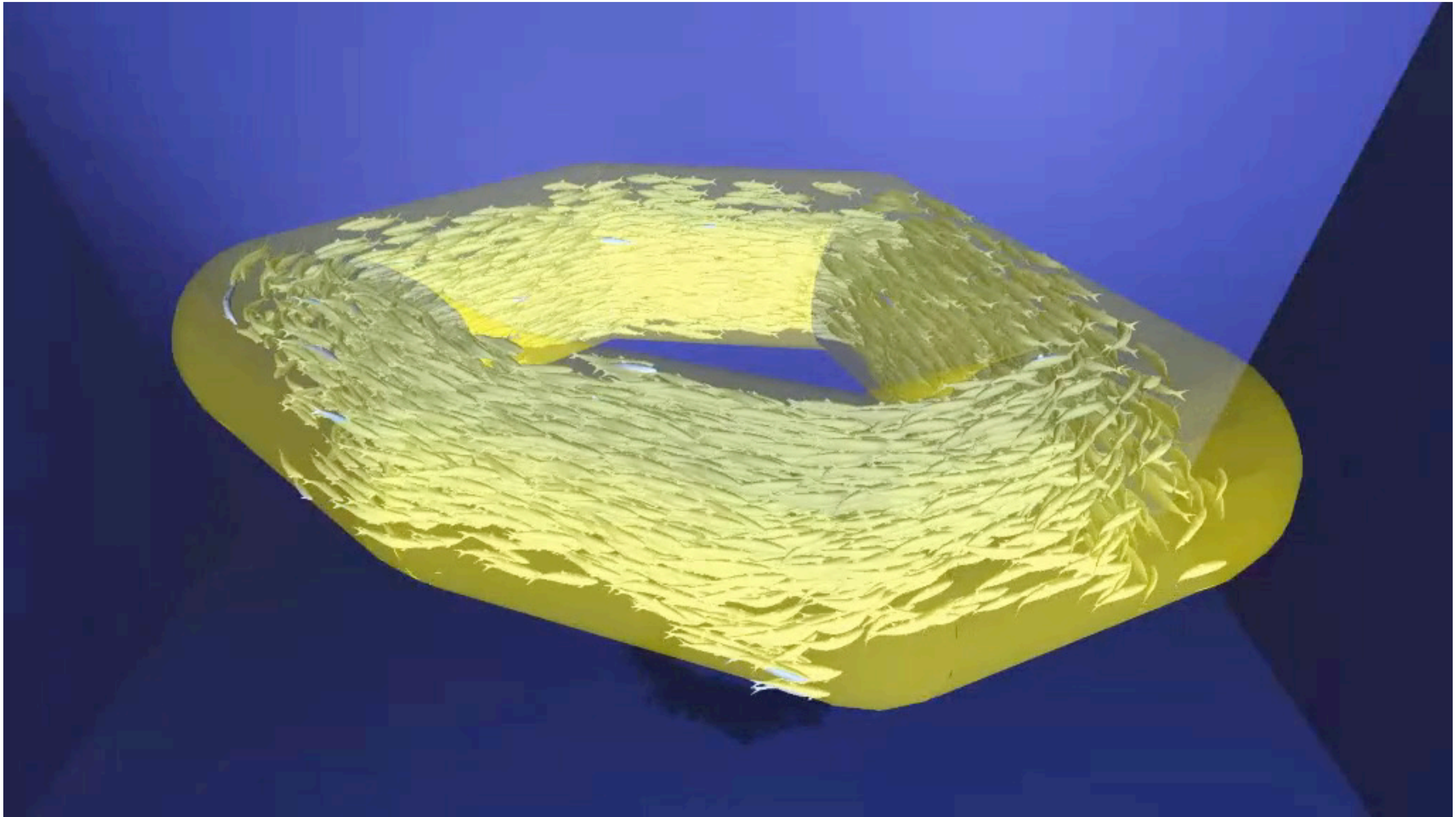
- If fish is inside the Link Area



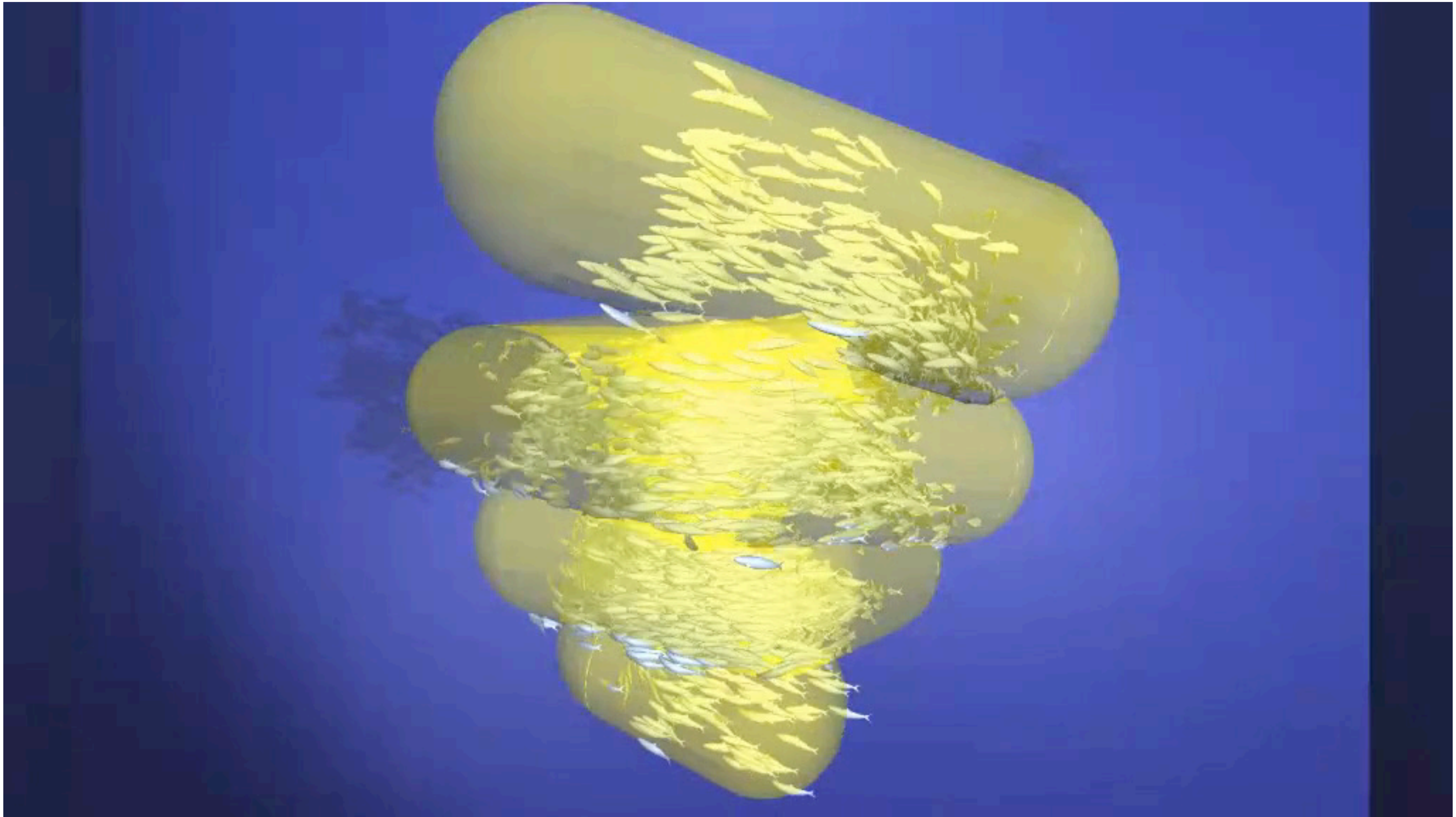
- If fish is outside the Link Area



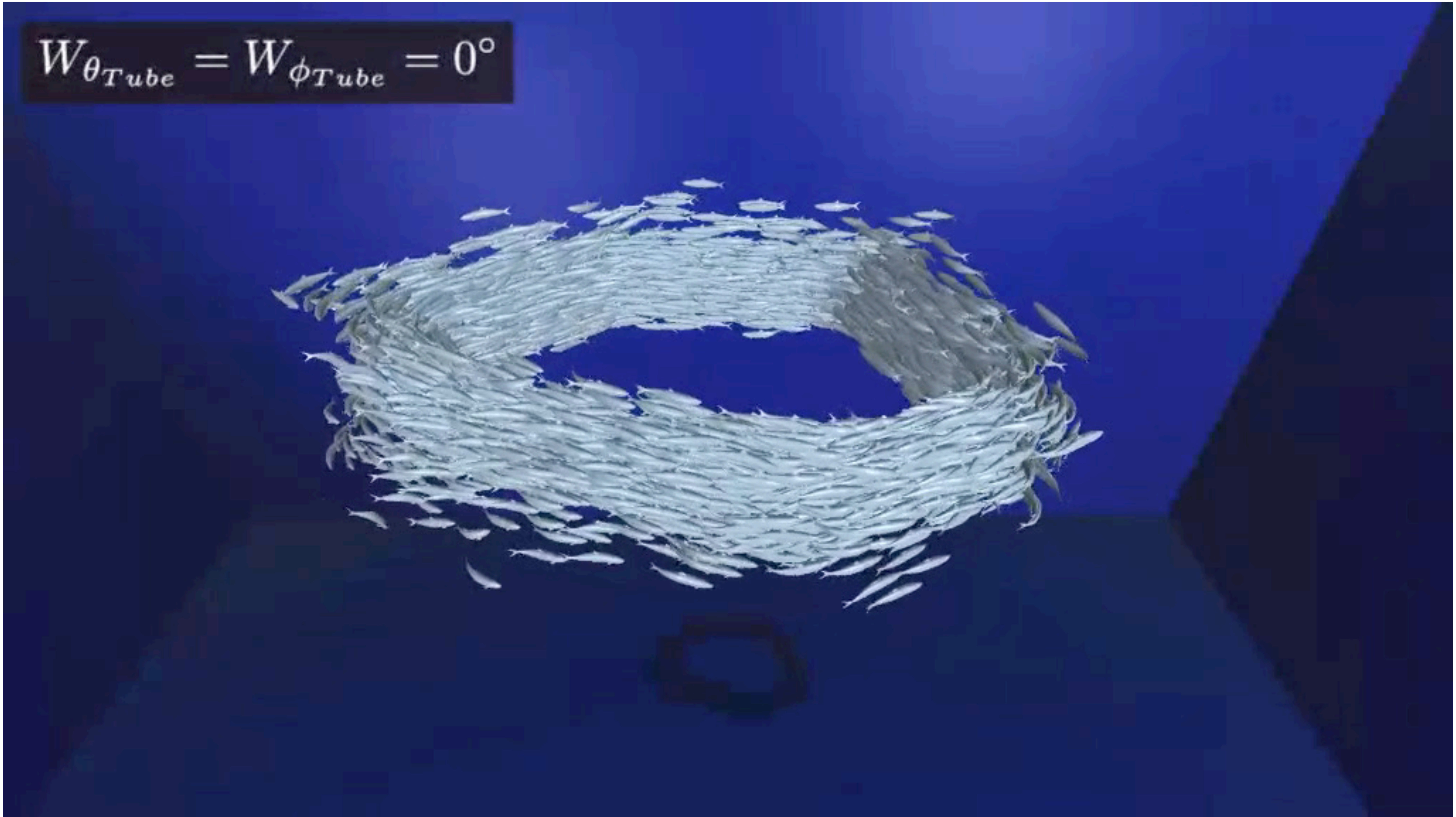
Results - Fish school - Torus



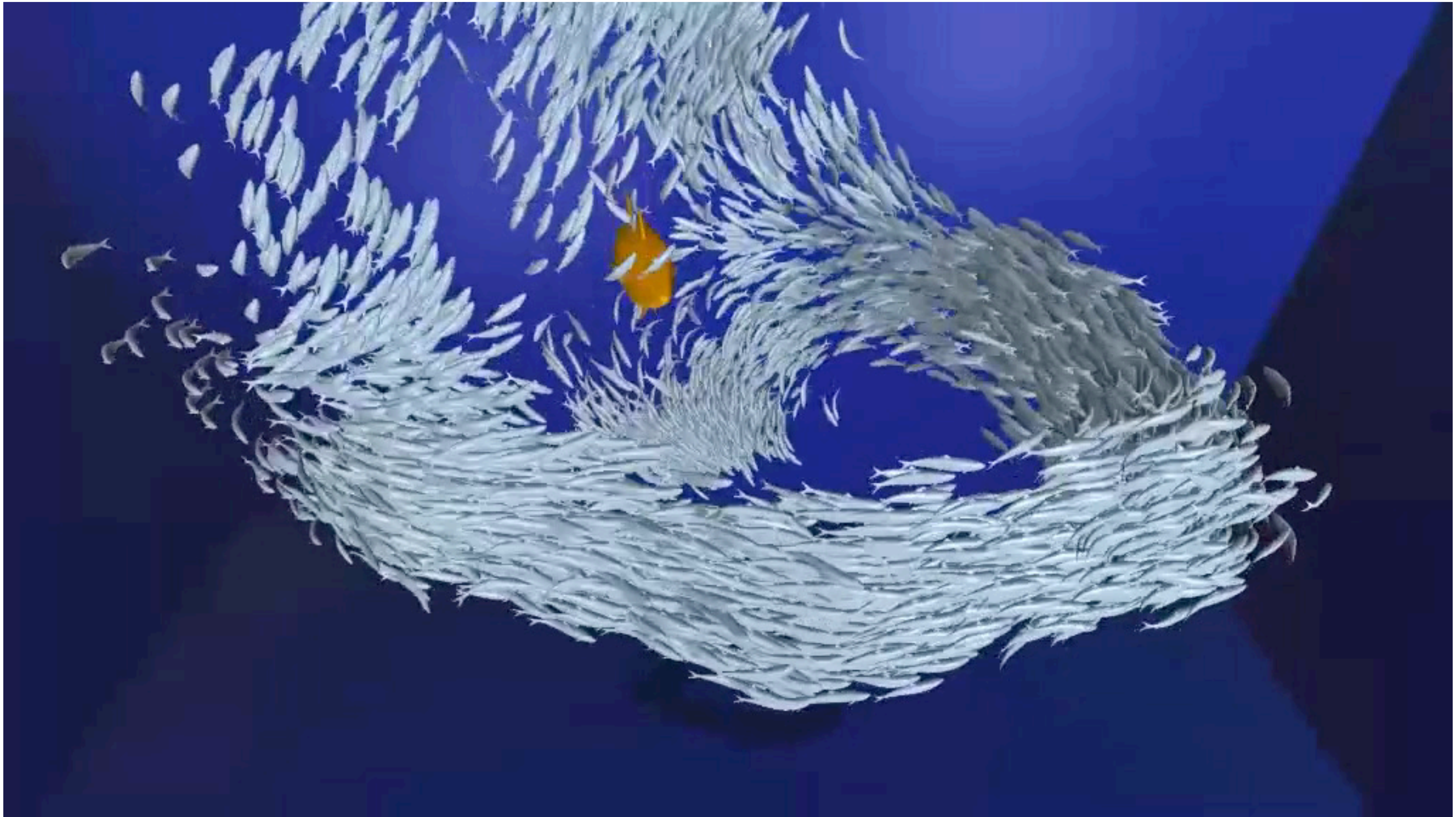
Results - Fish school - Tornado



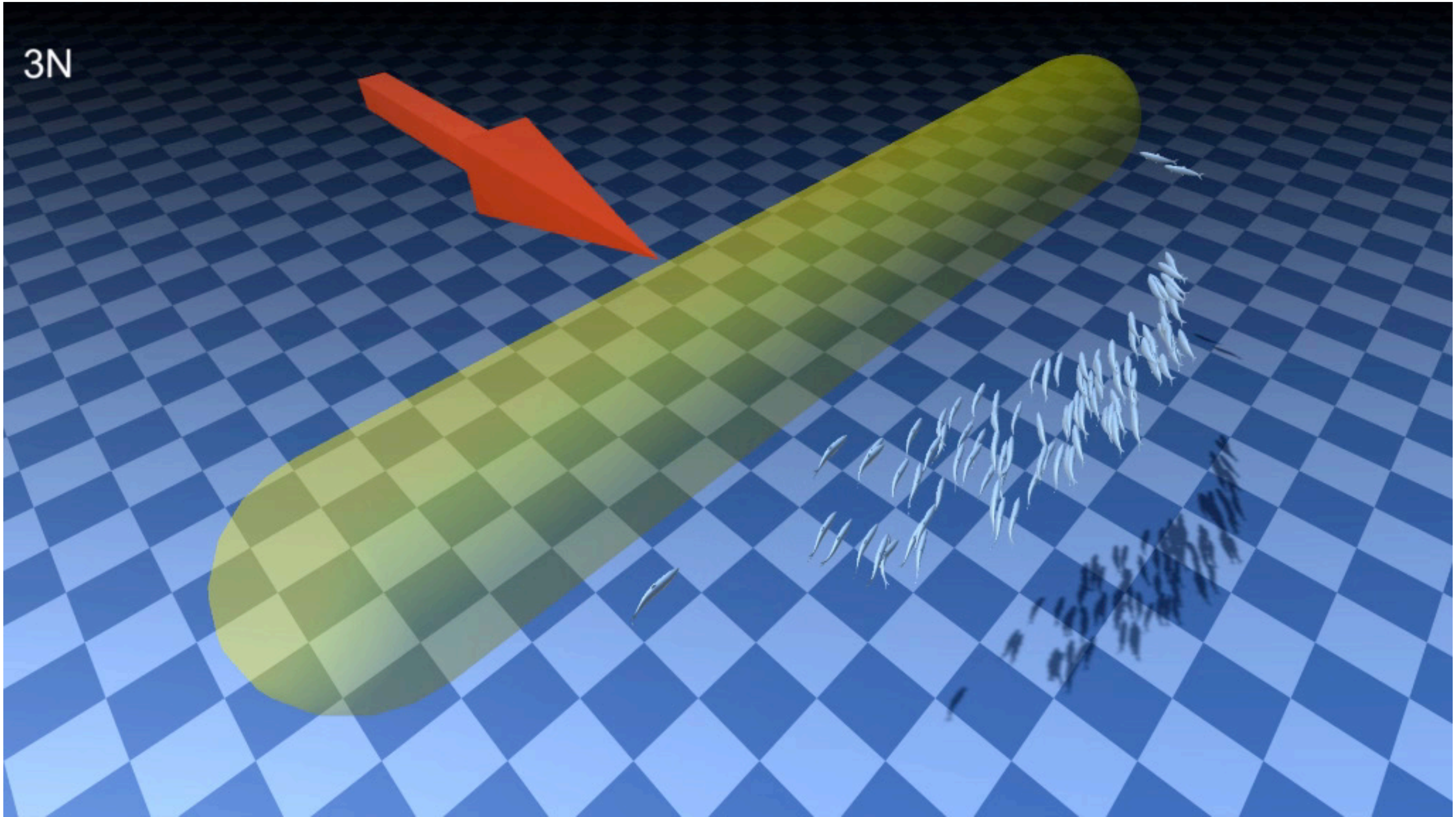
Results - Tube parameters comparison



Results - Escape from predator

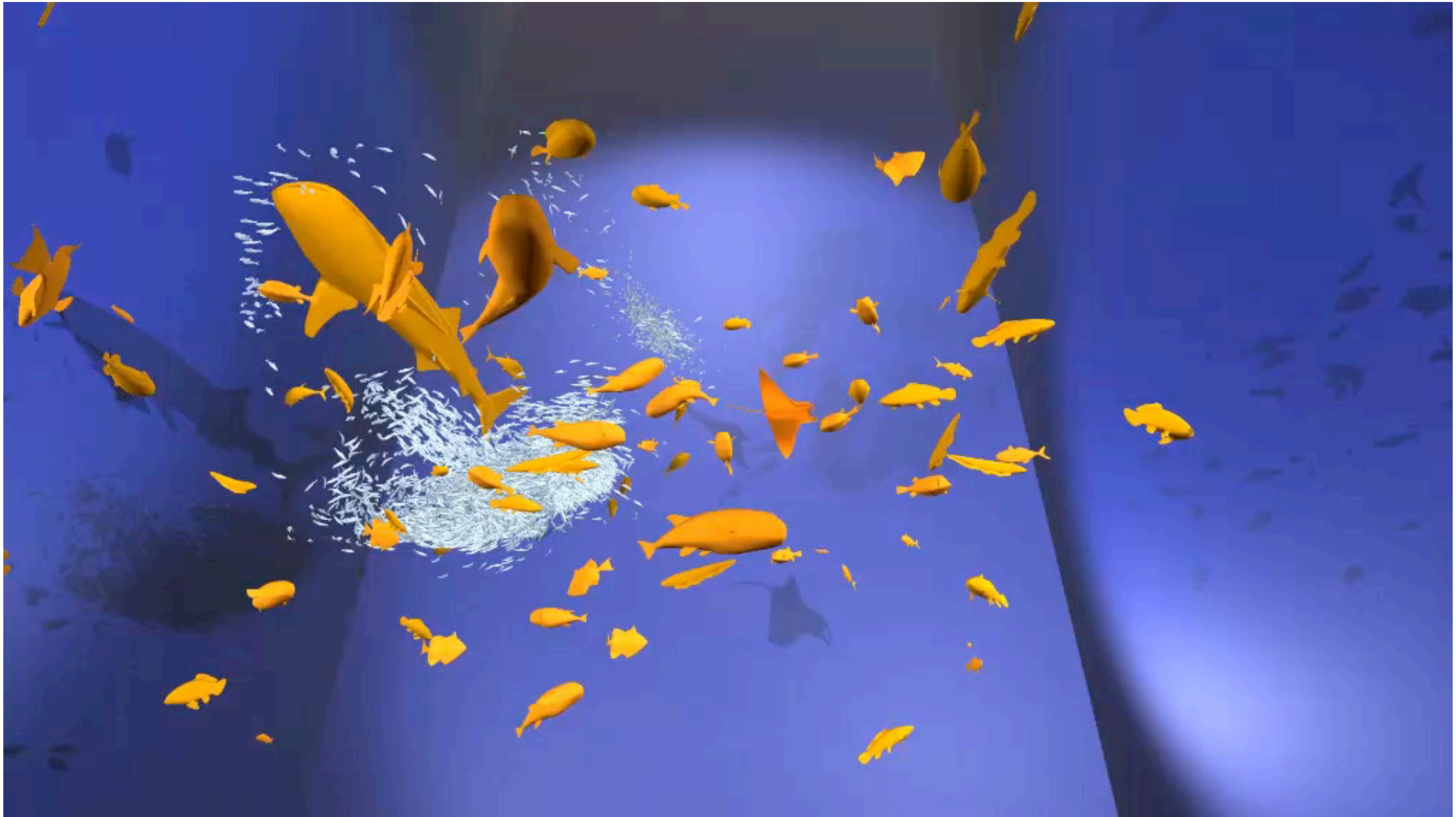


Results - Robustness



Results - Interactive Application

Results - 8,000 Pilchards + other 11 species



Results - 12,000 Pilchards + other 11 species with textures/lighting

Related works on fish-swimming simulation

fish-type autonomous agent
(control framework)
[Tu and Terzopoulos 1994]

Cognitive models
(high-level controller)

focus on
cognitive modeling
[Funge+ 1999]

Physical models
(low-level controller)

focus on
solid-fluid simulation
[Tan+ 2011]

Limitation

- Cannot simulate many fish due to fluid simulation
- Cannot simulate fully the variation of swimming styles

Position of our research

fish-type autonomous agent
(control framework)
[Tu and Terzopoulos 1994]

Cognitive models
(high-level controller)

Unified Motion Planner
(middle-level controller)

Physical models
(low-level controller)

focus on
cognitive modeling
[Funge+ 1999]

our research
[Satoi+ 2016]

focus on
solid-fluid simulation
[Tan+ 2011]

Our contribution

- Propose the middle-level controller
  to reproduce the variation of simple "swimming" action
- Achieve realistic motion control of a few thousands or more fish

Limitation and future works

- Our fish do not have physical output

  -> Reproducing physical interaction against environment is difficult

- Controllable joint types are limited

  -> Reproducing Goldfish's fins like cloth is difficult

- High-level behaviors are only "free swimming", "avoid", and "escape"

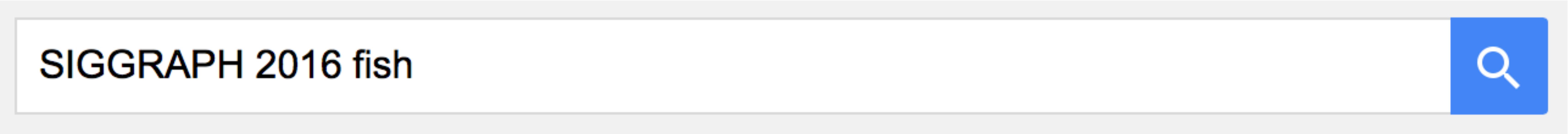
  -> Actual fish can conduct more various behaviors

    - bottom-feeding flounder
    - responding to attacks
    - predatory actions toward members of the same species based on territory

Thank you

Project page

- http://www.entcomp.esys.tsukuba.ac.jp/en/project/unified-motion-planner/
- Paper, Supplemental document, HQ video, and BibTeX



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