# Combining Behaviors

- A moving character – ***usually needs more than one steering behaviour*** to model it **more realistically**
- E.g. To seek its goal, avoid collision with others, avoid bumping into walls (all at the same time)
- Some special behaviours may require more than one steering behaviour to be active at once.
- E.g., to steer in a group towards a goal, maintaining a good separation distance from group members, and to match each members' velocities.
- How?

# Combining Behaviors

- **Blending**
  - **Execute all steering behaviours and combining their results *using some set of weights or priorities***
- **Arbitration**
  - **Selects one or more steering behaviours to have complete control over character. Many schemes available nowadays.**
- **Many steering systems *combine elements of both* blending and arbitration to maximize advantages**

# Weighted Blending

- **Use weights** to combine steering behaviours
- Example: Riot crowd AI
- In this example, the characters need to
  - move as a mass (*staying close to the center of mass of the group*), while
  - making sure that they *aren't consistently bumping into each other*.

- Character does not just do one thing. It does a "blend" or synthesis of all considered behaviours

http://commons.wikimedia.org/wiki/File:Tompkins_square_riot_1874.jpg

# Weighted Blending

- **Idea**:
  - **Each steering behaviour is asked for its acceleration request, $a_i$**
  - **Combine the acceleration using a weighted linear sum, weights $w_i$ specific to each behavior,**

$$a = w_1 a_1 + w_2 a_2 + \cdots + w_n a_n$$

  - **If magnitude of $a$, $|a|$, from sum is too great, trim it accordingly: $a = \min(a_m, |a|)\left(\frac{a}{|a|}\right)$**
- **There are *no constraints on the weights* – they *don't have to sum to one*.**
- **The group of steering behaviours are blended to act as a single behavior.**

# Weighted Blending

- **Idea**:
  - Each steering behaviour is asked for its acceleration request, $a_i$
  - Combine the accelerations using a weighted linear sum, weights $w_i$ specific to each behavior,

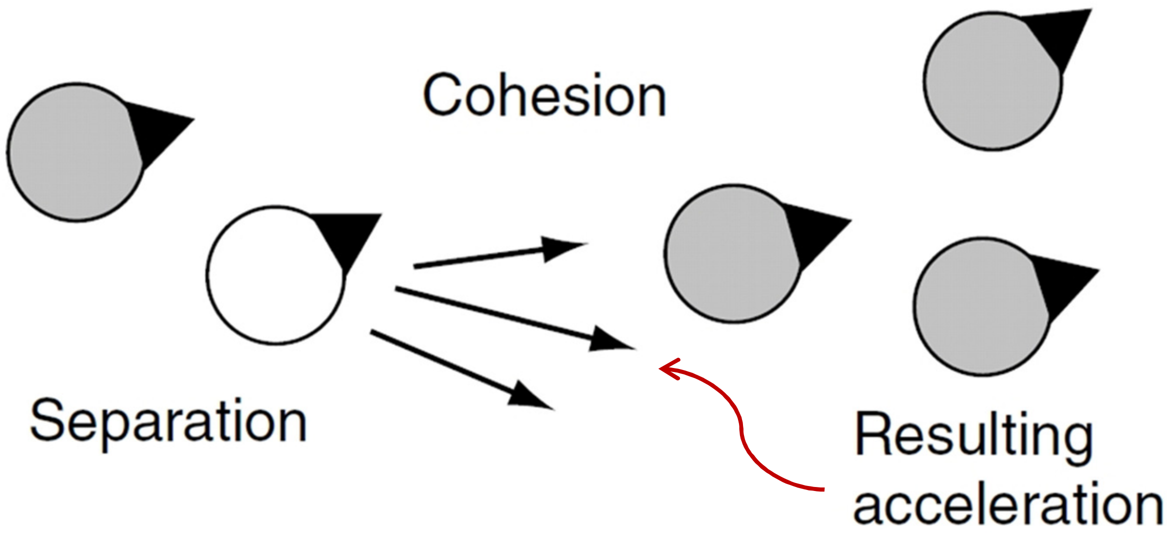
$$a = w_1 a_1 + w_2 a_2 + \cdots + w_n a_n$$

  - If magnitude of $a$, $|a|$, from sum is too great, trim it accordingly: $a = \min(a_m, |a|)\left(\frac{a}{|a|}\right)$
- There are *no constraints on the weights* – they *don't have to sum to one*.
- The group of steering behaviours are blended to act as a single behavior.

Université Concordia University

# Weighted Blending

- In our riot crowd example, we may use weights of $w_i = 1$ for ***both separation and cohesion***.
- In this case the requested accelerations are **summed and cropped to the maximum possible acceleration**. This is the output of the algorithm

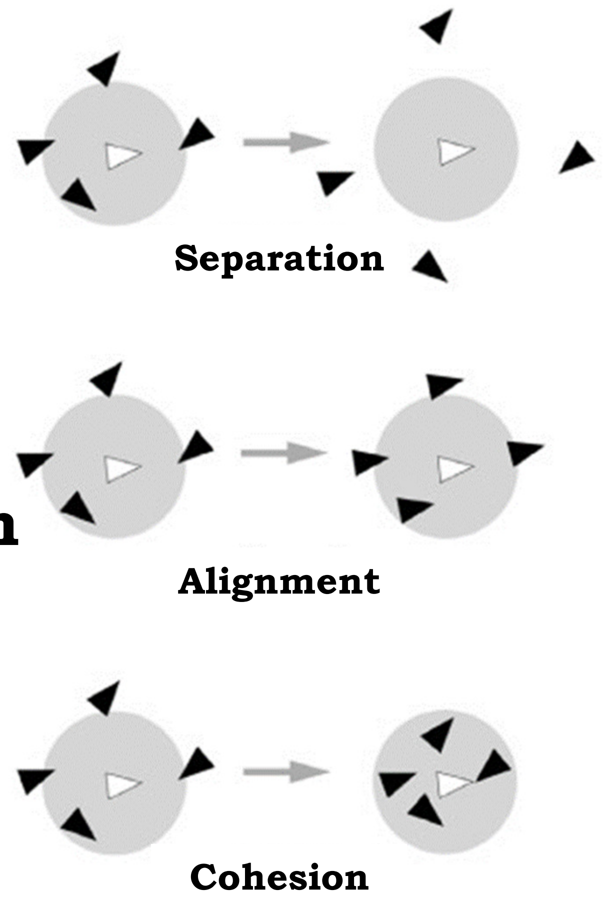


# Weighted Blending

- How to choose *appropriate weights* for multiple behaviours?
  - As in all parameterized systems, the choice of weights needs to be the subject of *inspired guesswork*, or *good trial and error*.
  - Could also try to use dynamic weights, but autonomous systems (using, for example, machine learning) don't work well.

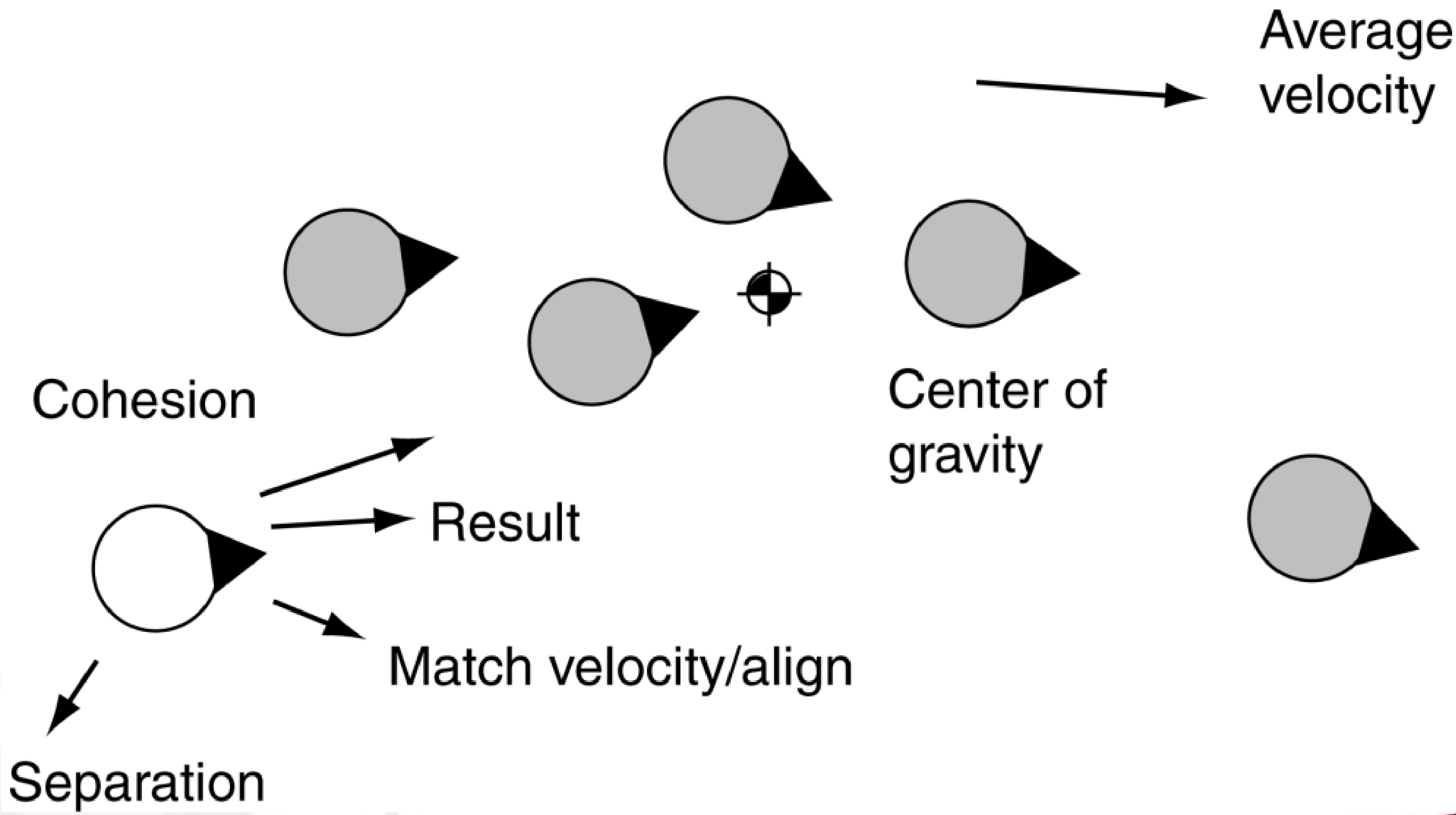
# Flocking

- Original research by **Craig Reynolds**, to model movement ***patterns of flocks of simulated birds*** ("boids").
- Flocking relies on simple weighted blend of 3 behaviours:
  - **Separation** – ***move away*** from boids that are too close
  - **Alignment** – ***move in the same direction*** and at the same velocity as flock
  - **Cohesion** – ***move towards the center of mass*** of the flock



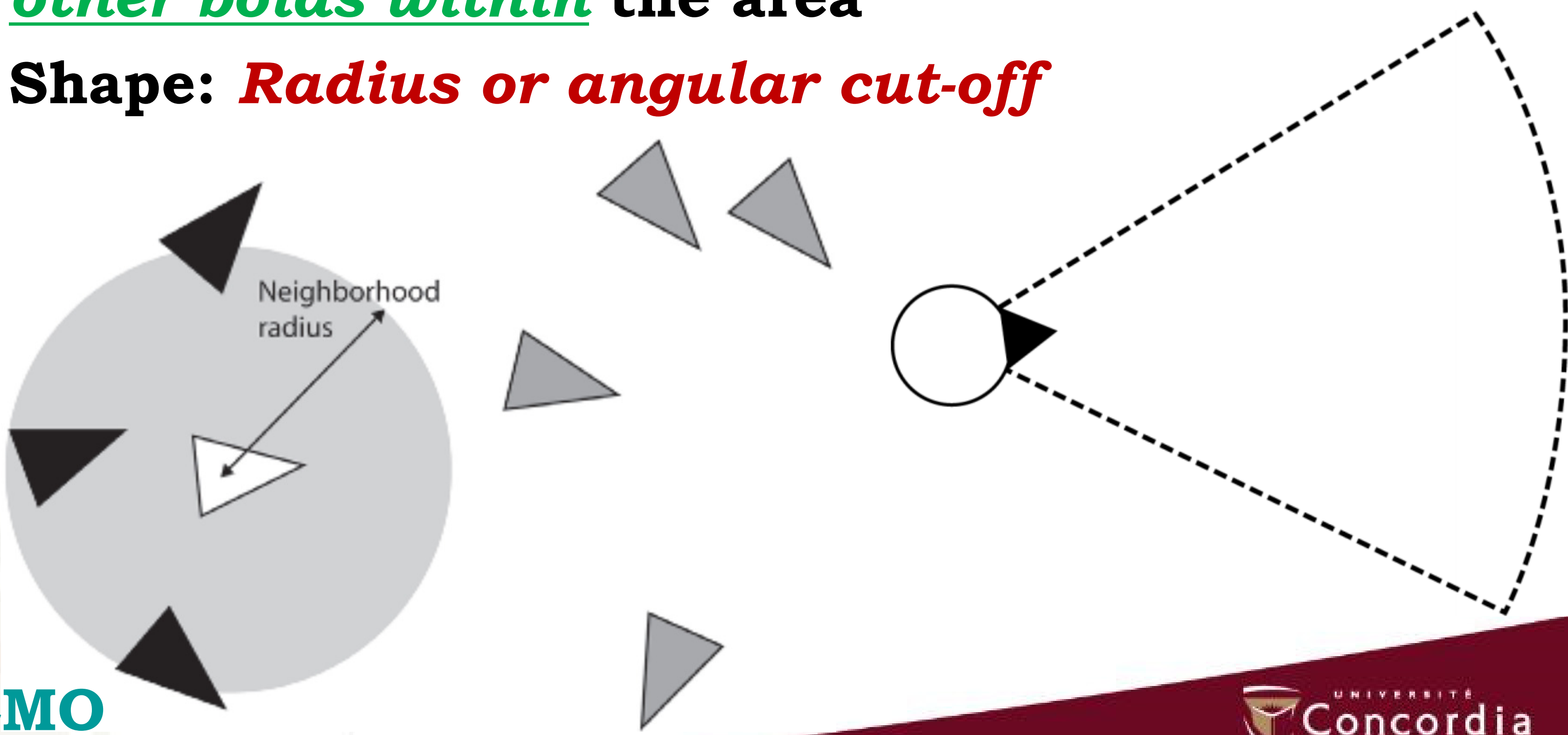
# Flocking

- **Simple flocking**: ***Equal weights for all***



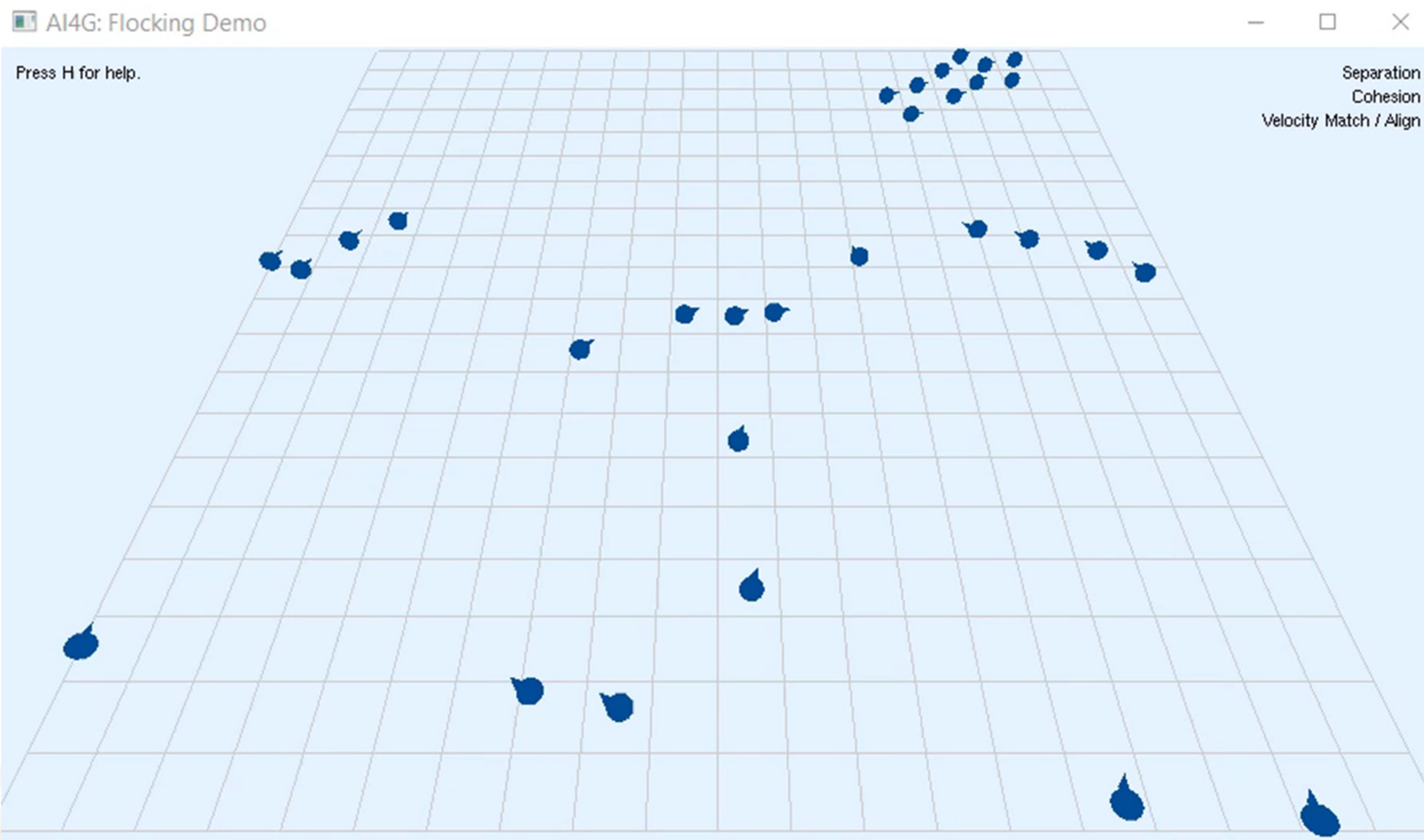
# Flocking

- In most implementations, flocking behaviour is modified to *ignore distant boids for efficiency*
- A neighborhood is specified to *consider only other boids within* the area
- Shape: *Radius or angular cut-off*



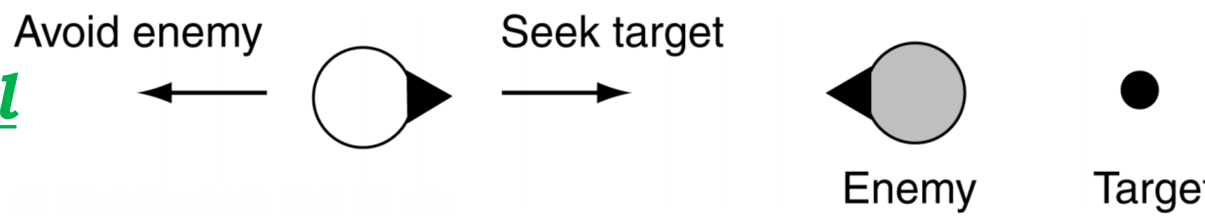

DEMO

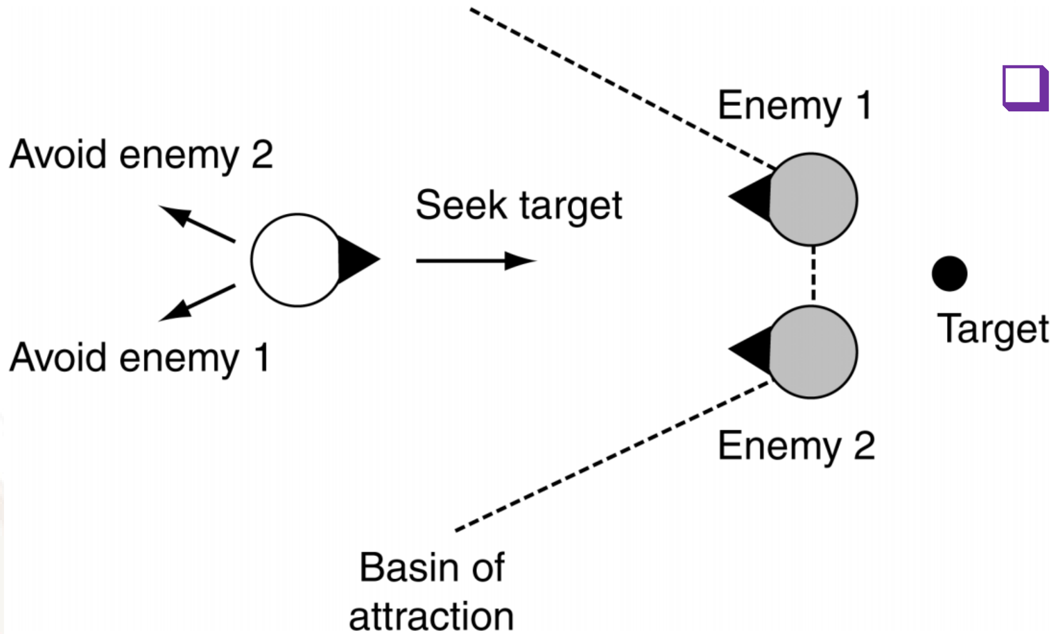
# Flocking


AI4G: Flocking Demo
Press H for help.
Separation
Cohesion
Velocity Match / Align

# Equilibria Problems

- **Unstable equilibria**: **Character trying to do *<u>more than one thing</u>* at a time, resulting in <u>doing nothing</u> (as long as enemy is stationary) since the *<u>accelerations exactly cancel</u>***

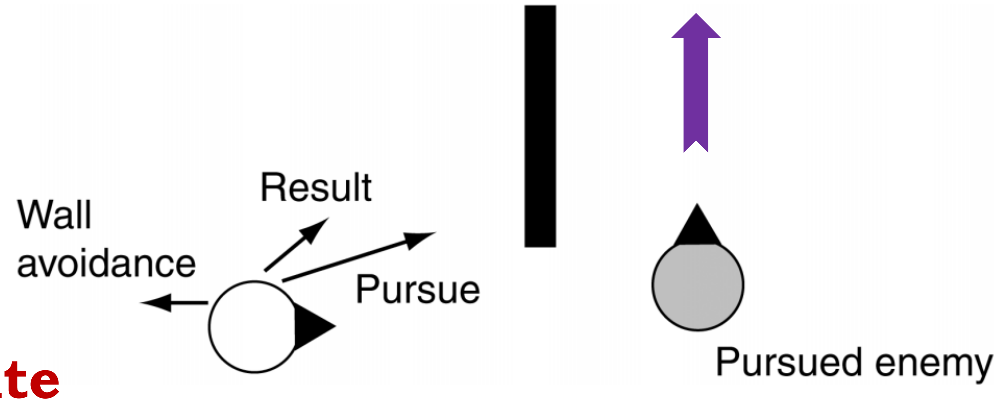


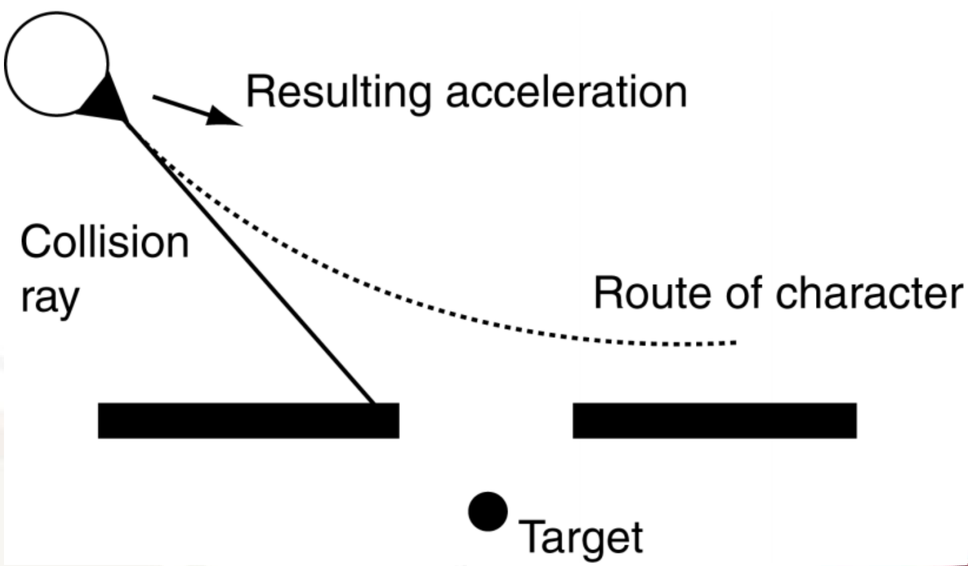

- **Stable equilibria**: **Character could make it *<u>out of equilibrium slightly</u>*, but heads back into equilibrium within <u>basin of attraction</u>**

# Constrained Envir…

- **Obstacles Vs Target**: Character tries to avoid obstacle while pursuing enemy. **Blending causes resulting direction even farther from correct route to capture enemy**

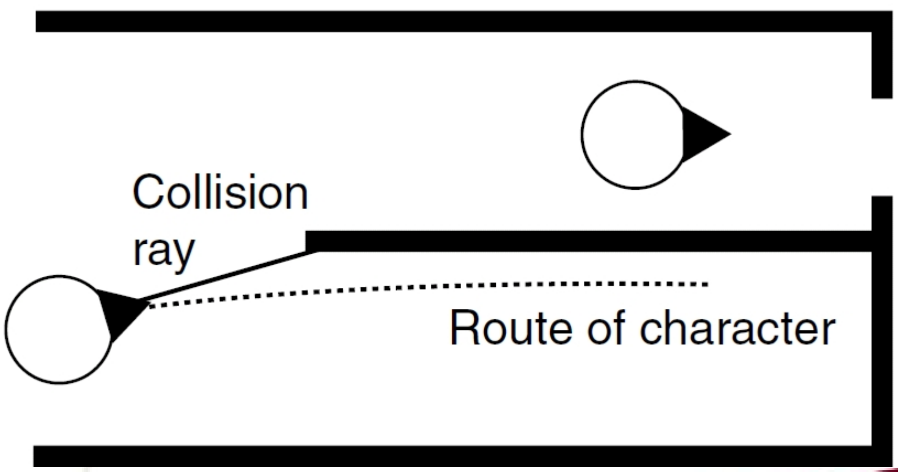



- **Narrow Doorways**: Character tries to move at acute angles through narrow doorways to get to target. Obstacle avoidance causes the ***character to move past the door missing the target***



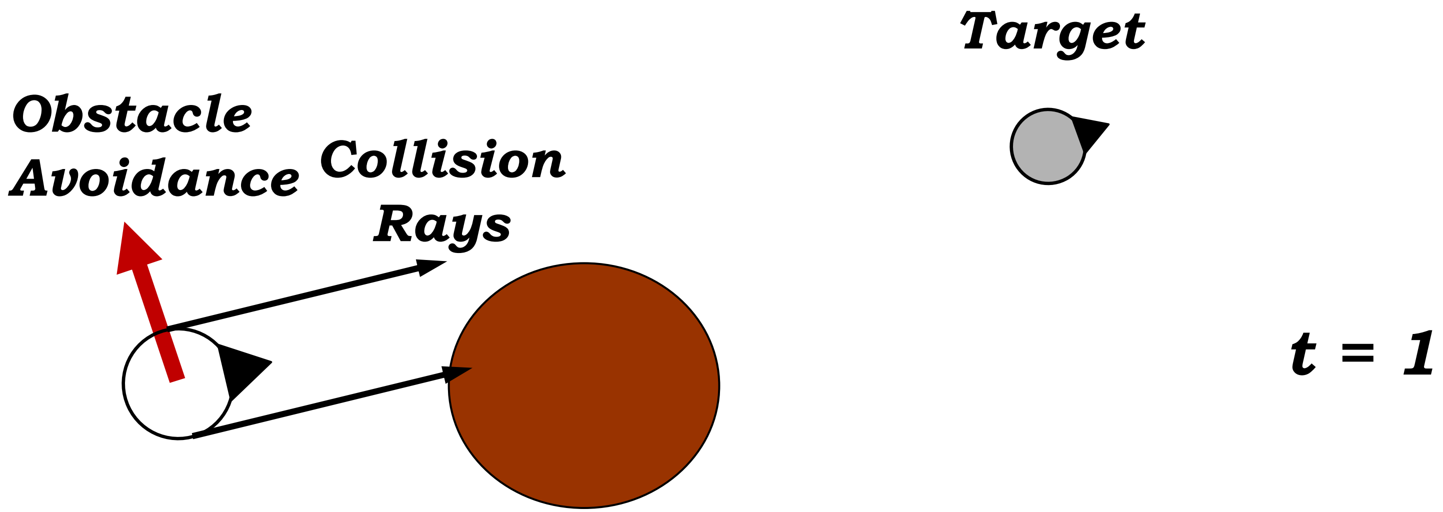
# Nearsightedness

- **Nearsightedness**: **Due to the behaviours acting locally in their immediate surroundings, a character can avoid a wall, but *takes the wrong side of the wall* due to method of computing change of orientation.**
- ***Does not realize the wrong path*!**
- **Can be addressed by *incorporating pathfinding*.**



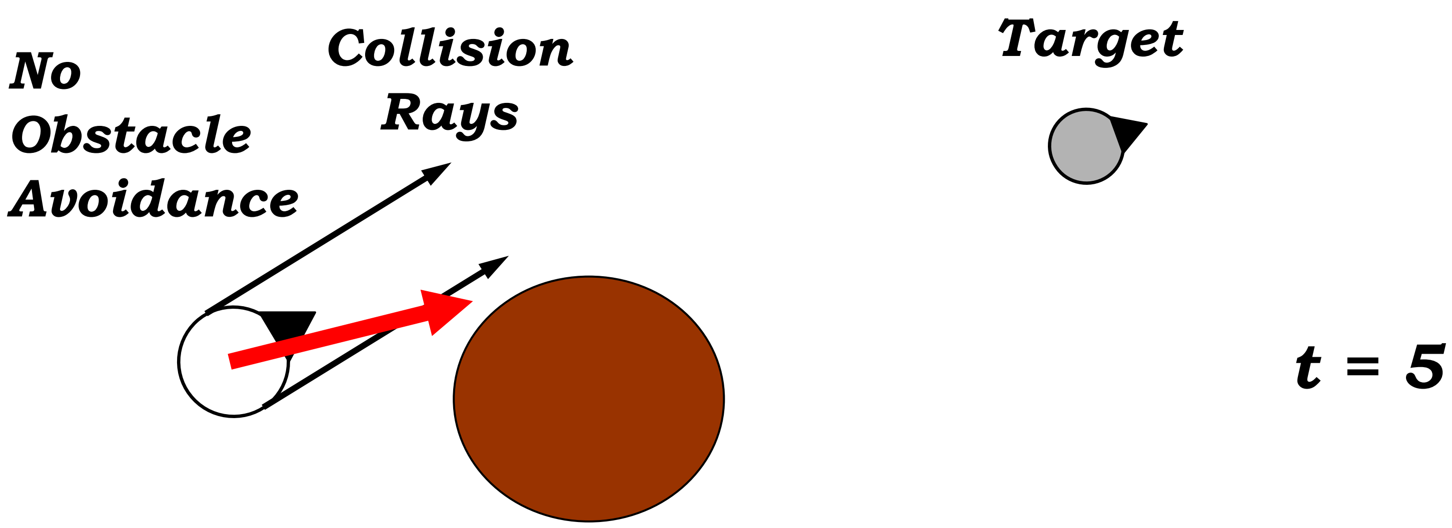
# Judder

- **Definition**: To vibrate with intensity



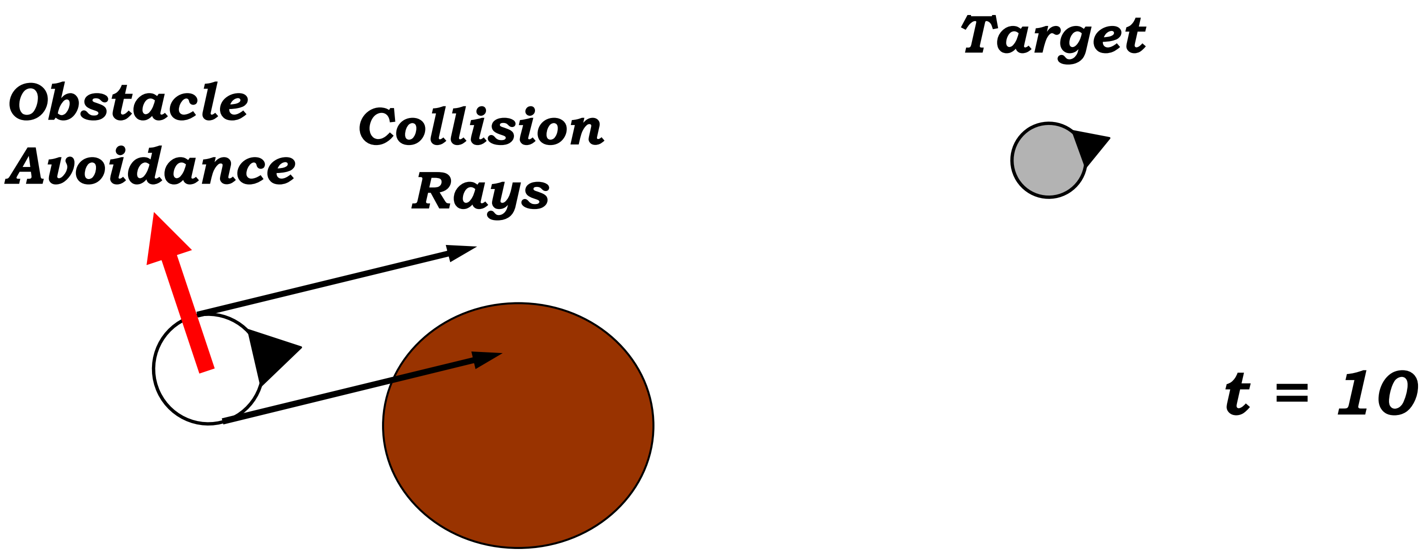
# Judder

- **Definition**: To vibrate with intensity



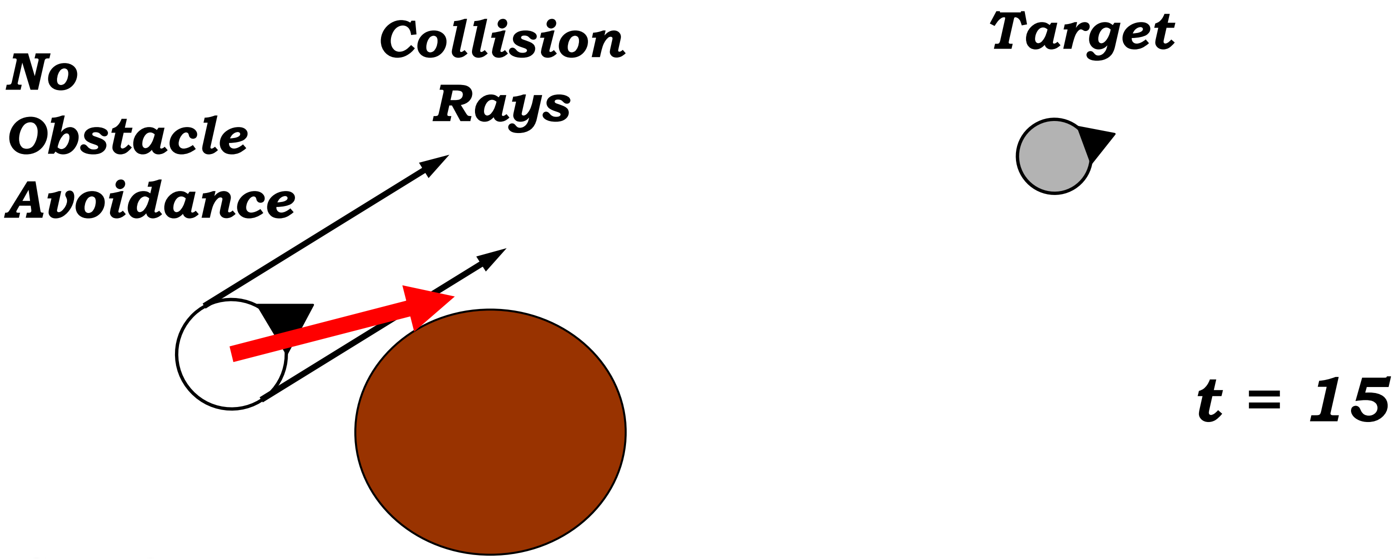
# Judder

- **Definition**: To vibrate with intensity



# Judder

- **Definition**: To vibrate with intensity



# Priority-based Blending

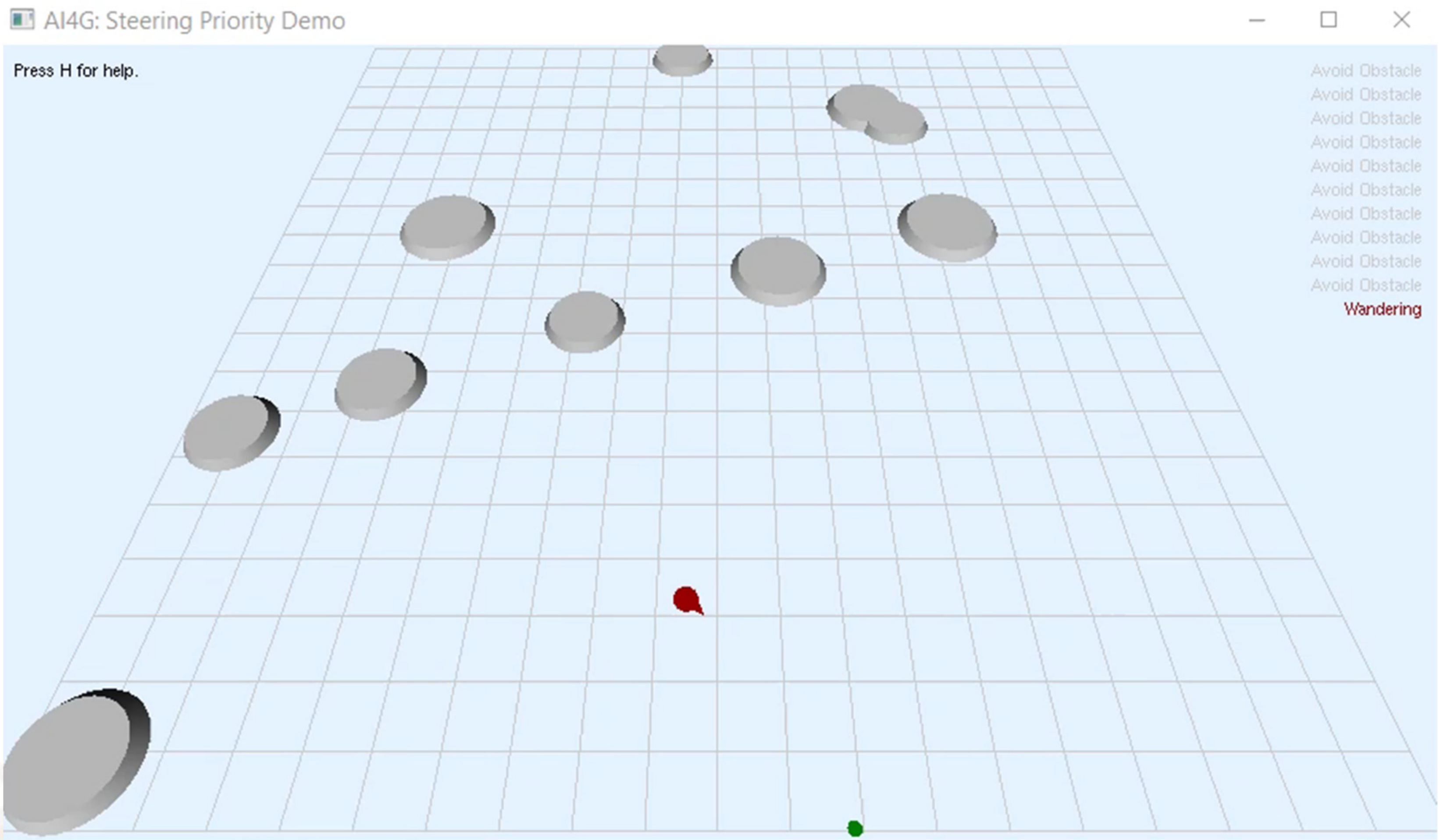
- **Some steering behaviours do not produce any acceleration as output in most situations (*Collision avoidance, Separation*, *etc.*) HOW?**
- **Others such as *Seek* and *Evade* which always produced an acceleration.**
- **So, when blended together some behaviour acceleration requests are *diluted by other behaviours***
- **Example: Seek (always max acceleration) + Collision Avoidance (minimal change of movement to avoid).**
- ***Seek always dominates if blended equally*!**

# Priority-based Blending

- **Idea**:
  - **Arrange behaviours in groups with regular blending weights**
  - **Place groups in order of priority, and consider each group accordingly**
    1. **If total result is very small (less than some threshold), ignore it and *consider next group***
    2. **If total result is reasonable (more than some threshold), use the result to *steer character***
- **Example: Pursuing character with 3 groups in priority → 1st: *Collision avoidance*; 2nd: *Separation*; 3rd: *Pursuit***
- **DEMO**

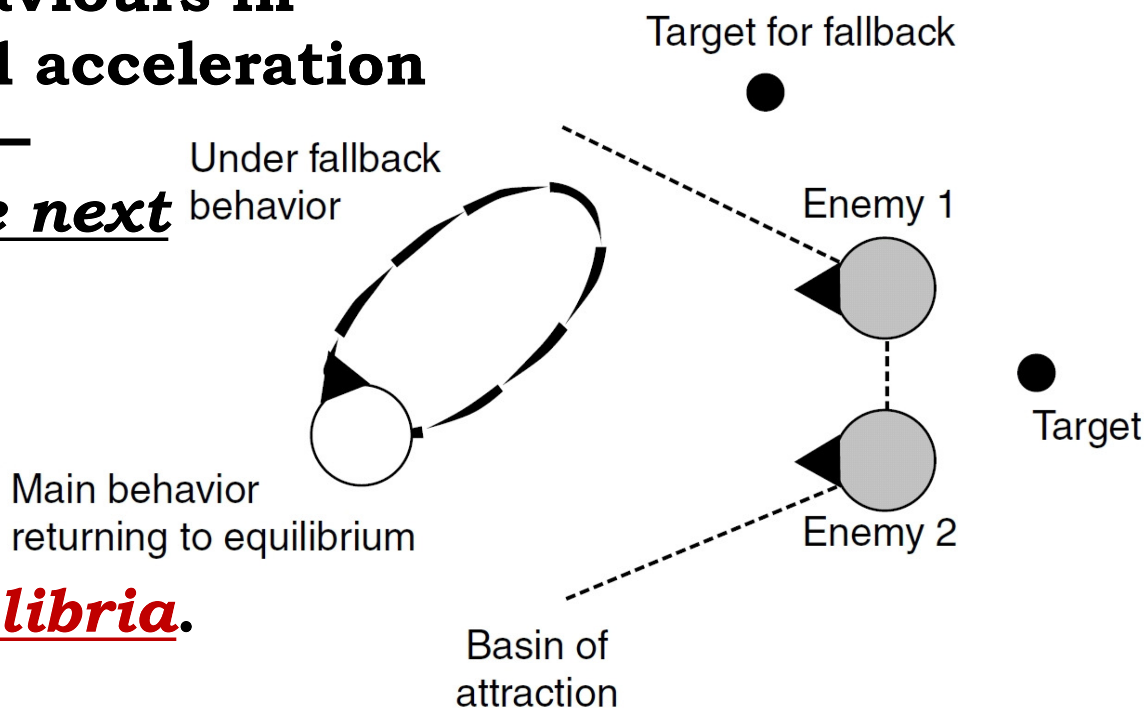
Université Concordia University

# Priority-based Blending



# Equilibria Fallback

- Priority-based approach ***can cope with unstable equilibria problem***.
- If a group of behaviours in equilibrium, total acceleration will be near zero – ***drop down to the next group in priority***
- Example: Falling back to ***Wander***
- But ***can't avoid large stable equilibria***.



# Variable Priorities

- If we want more control to be able to avoid equilibria problems, *etc.*, instead of a fixed order to represent priority values, we can allow ***each group of behaviours return a dynamic priority value***.
- These groups are then sorted by priority values and the algorithm continues as before.
- Although an obvious extension, the resultant practical advantages are minor and ***a full cooperative arbitration system*** (discussed next) may as well be used…

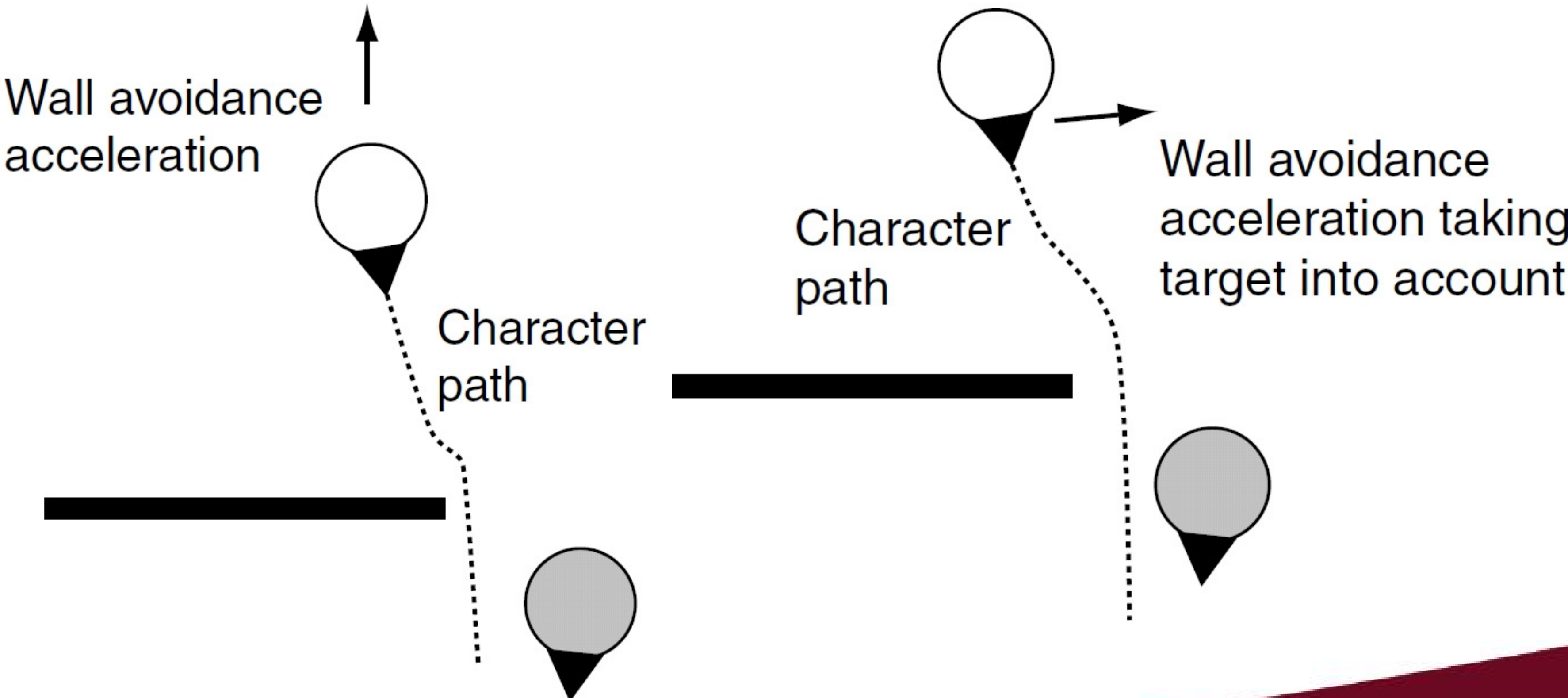
Université Concordia University

# Cooperative Arbitration

- **Main problems** with approaches so far:
  - In weighted blending, one of the main behaviours *may be diluted* by the output of another behaviour
  - In priority blending, a prioritized behaviour *may have a drastic effect* on the character movement (not smooth) when it changes to other behaviours of less priority
- *Context-sensitivity* or *cooperation* between different behaviours can help create more realistic and less-dramatic movement

# Cooperative Arbitration

- Consider an example of a character chasing a target using <u>Pursue</u> while *avoiding collisions* with walls.



# Cooperative Arbitration

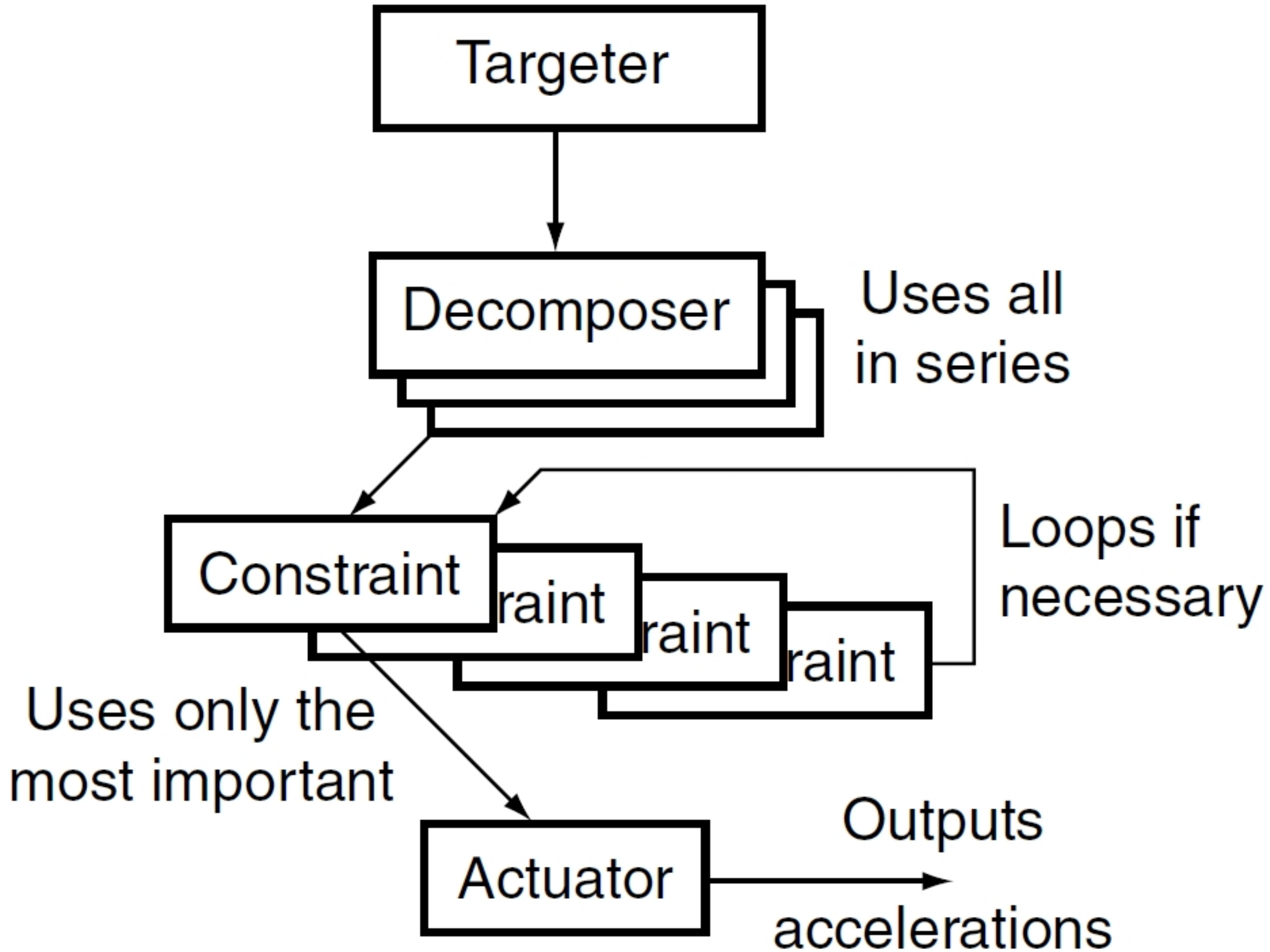
- **A <u>cooperative arbitration</u> approach that <u>*allows constructive interaction*</u> between steering behaviours.**
- **It *provides excellent performance* in a range of situations that are normally problematic, including *tight passages* and *integrating steering with pathfinding*.**
- **One of many possible approaches; not the only way.**
- **<u>Not widely used</u>, though.**

Université Concordia University

# Cooperative Arbitration

- ***Increases the complexity*** **of the steering algorithm as the simple building blocks must now collaborate.**
- **Collaborative arbitration implementations:**
  - **Decision making, Decision trees**
  - **State machines**
  - **Blackboard architectures: each behaviour is an expert that can read (from the blackboard) what other behaviours would like to do before having its own say**
- ***No de facto standard for games***
- **For an example, we'll look at the *steering pipeline algorithm*...**

# Steering Pipeline



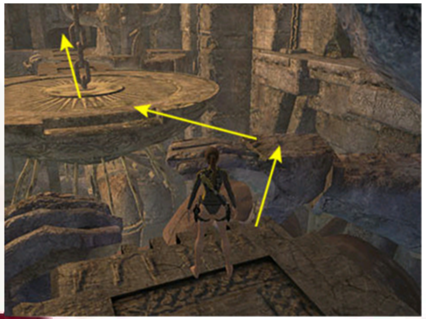
# Steering Pipeline

- There are four stages in the pipeline:
  1. the ***targeter*** works out where the top-level movement goal is,
  2. the ***decomposers*** provide sub-goals that lead to the main goal,
  3. the ***constraints*** limit the way a character can achieve a goal, and
  4. the ***actuator*** limits the physical movement capabilities of a character.
- In all but the final stage, there can be one or more components. **All are steering behaviours**.
- **DEMO**

# Steering Pipeline

# Jumping

- First Person Shooter, Action, *etc.*, genre games need *jumping as part of the character movement*
- Jumping is not part of steering mechanisms
- Jumps *can be failures*
  - Character tries to jump from one platform to another but fails
  - *Cost of error larger* than for steering
    - Slight errors using steering behaviours while pursuing are *corrected almost immediately*

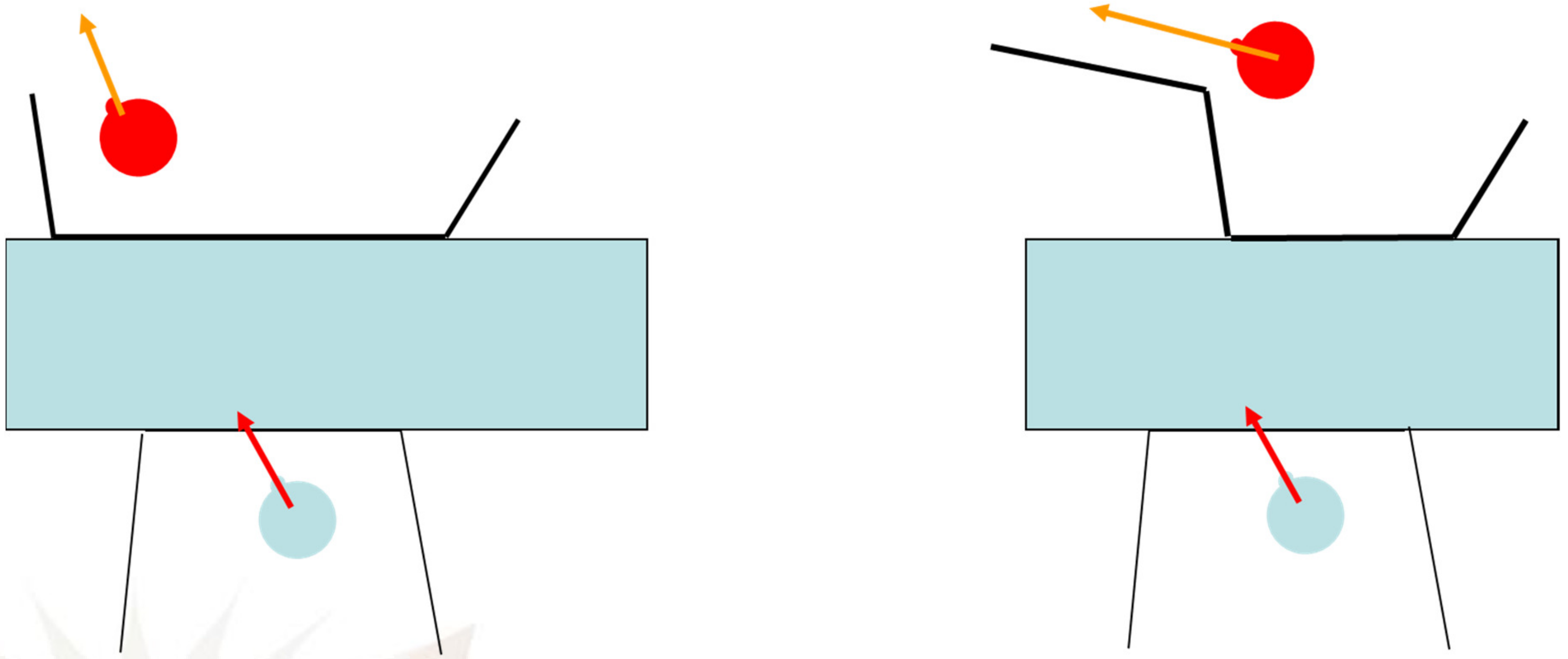


http://www.tombraiderchronicles.com/underworld/walkthrough/level02-2.html

Université Concordia University

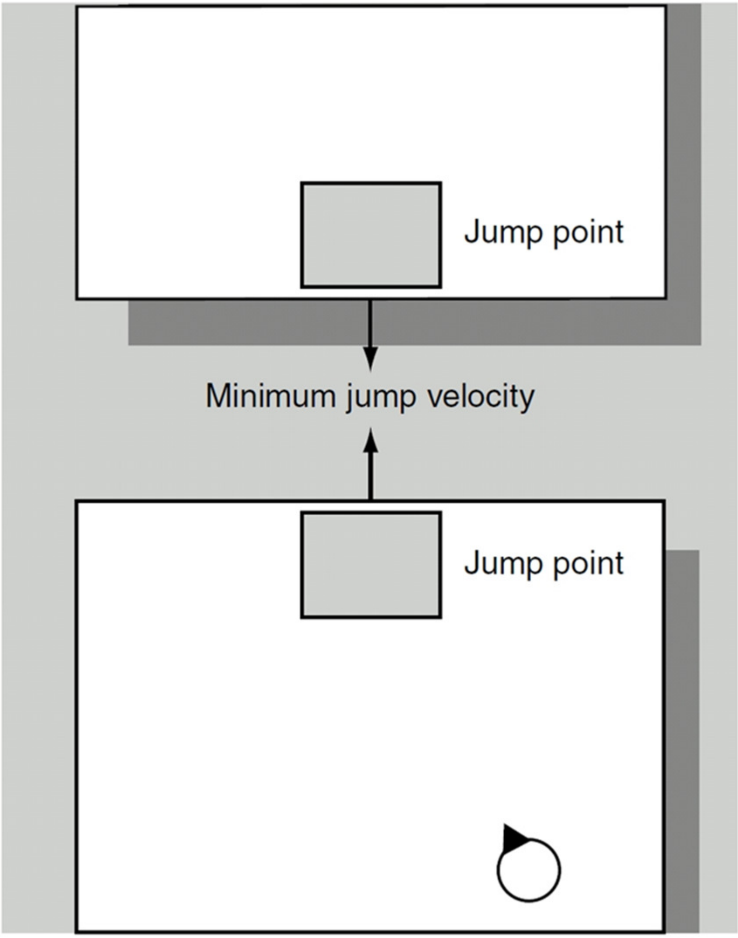
# Jumping

- Character <u>must set up for jump on the right</u>, but <u>not on the left</u>:



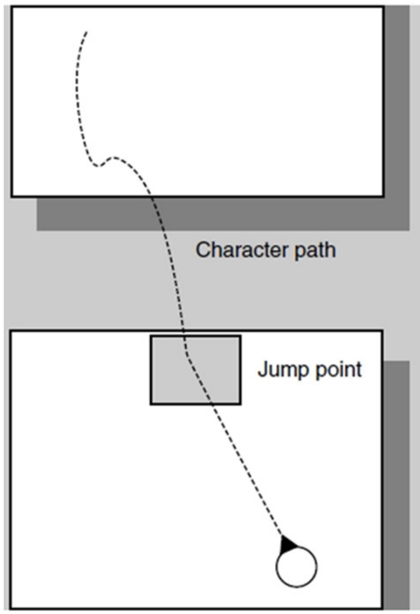
# Jump Points

- The simplest support for jumps ***puts the onus on the level designer***.
- ***Locations in the game level*** are labelled as being **jump points**. These regions need to be manually placed.
- If characters can move at many different speeds, then jump points ***also have an associated minimum velocity set***.



# Jumping

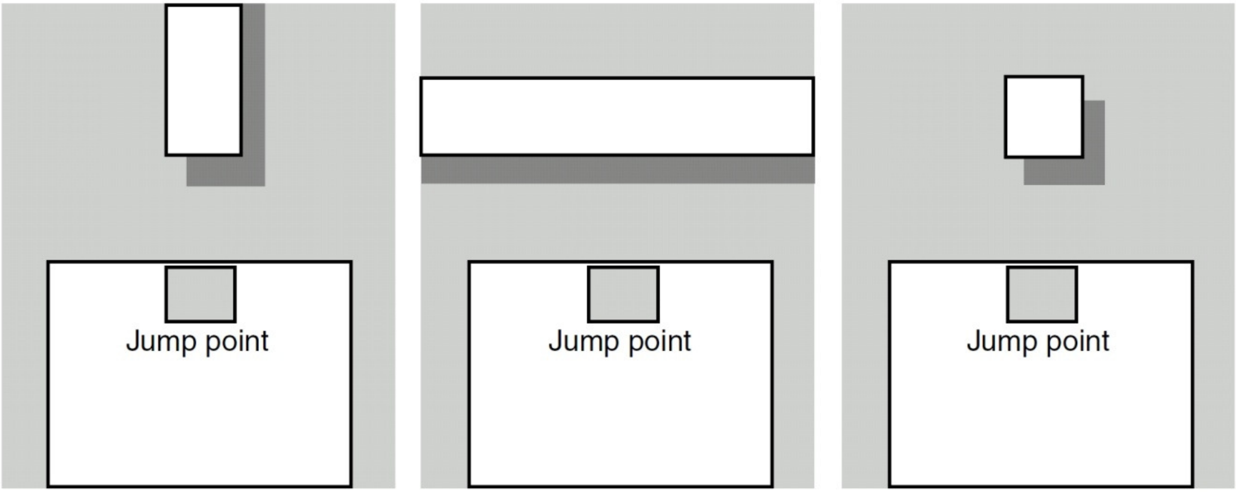
- Character uses the *velocity matching* steering mechanism to make the jump:
  - Character decides to take the jump
    - *Pathfinding* decides that character needs to jump (this gives also *type of jump*), OR
    - Simple steering mechanism drives character over edge (this needs look ahead to determine type of jump)




- New steering behavior to do velocity matching to reach the jump point with the correct velocity
- When character reaches jump point, *a jump action is executed*

# Jumping - Weakness

- Jumps are ***difficult to make*** if:




- Create jump points for characters in level design
  - **Player characters can try to make difficult jumps**, but ***AI characters cannot***
  - **Minimize number of occasions where this limitation becomes obvious**
    - **Level design needs to *hide weaknesses in the AI***

# Jumping – Landing Pads

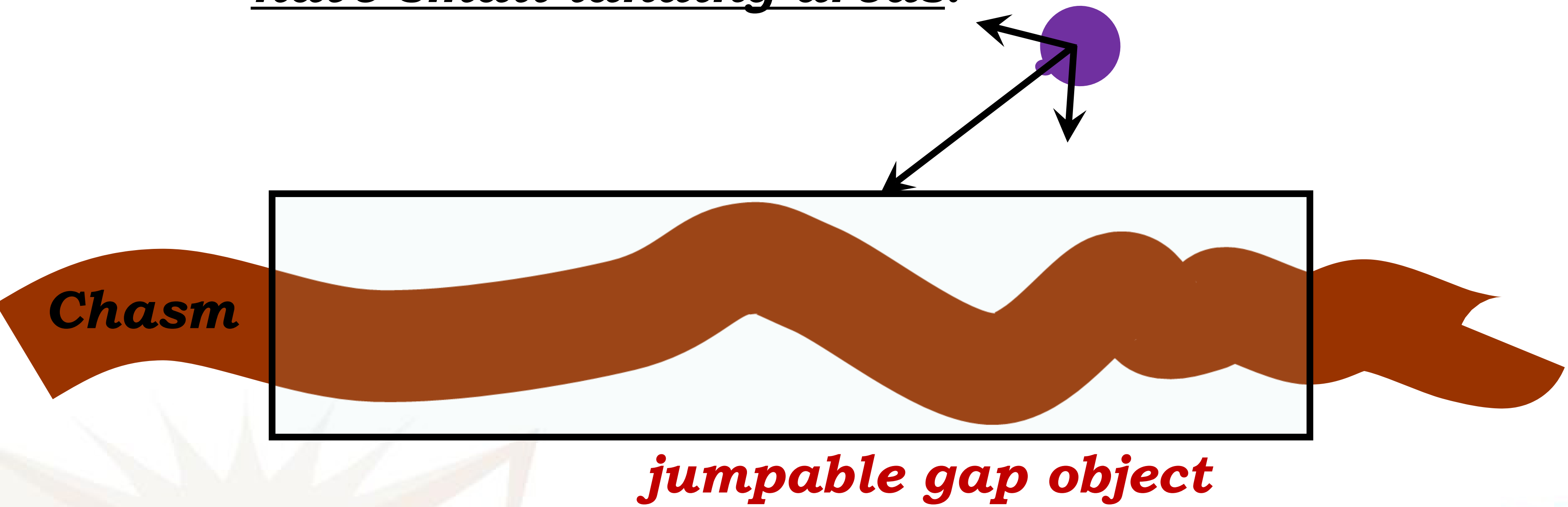
- A better alternative uses *pairs of jump points and landing pads* (very much like jump points)
- Rather than require the level designer to set up the required velocity, we can leave that up to the character.
  - When character decides to make the jump, add an additional step:
    - Use trajectory prediction code to calculate velocity required to reach landing area
      - This allows characters to take their *own physics* (weight, load, strength) into account
- Use velocity matching steering algorithm

# Jumping – Hole Fillers

- Another approach allows characters to *choose their own jump points*
- Create an invisible "jumpable gap" object to fill the hole as part of certain obstacles
- Change obstacle avoidance behaviour to a "jump detector" behaviour:
  - When detecting collision with a jumpable gap, character runs towards gap *at full speed*.
  - Just before the gap, character leaps into air
- Characters are *not limited to a particular set of locations* from which they can jump.

# Jumping – Hole Fillers

- **Works well <u>if landing area is large</u>**
- **<u>Fails for small landing areas</u>**
  - **In this case, *<u>ensure</u>* that level design *<u>does not have small landing areas</u>*.**



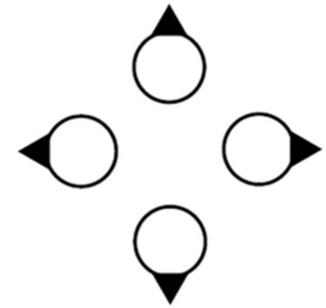
# Coordinated Movement

- Done by groups of characters
- Coordinated movement can occur at two levels
  - can result from **individual decisions** *that complement each other* (so that their movement looks coordinated)
  - can result from decisions made by the group as a whole
- We will focus on formation motion which is the movement of a group of characters so that they *retain some group organization*.
- We will consider tactical decision making later.

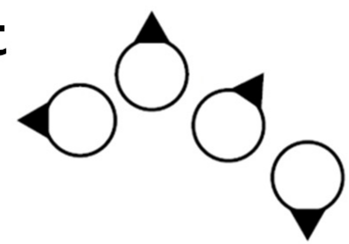
# Fixed Formations

- **Simplest kind:** **Fixed geometric formations**
  - **Usually with *a designated leader***
  - **Leader moves *as an individual*, everybody else moves *based on leader's position***
  - **The movement of the leader character should take into account the fact that *it is carrying the other characters with it*.**
  - **Actual positions determined from formation**

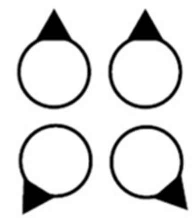
Line



Defensive Circle



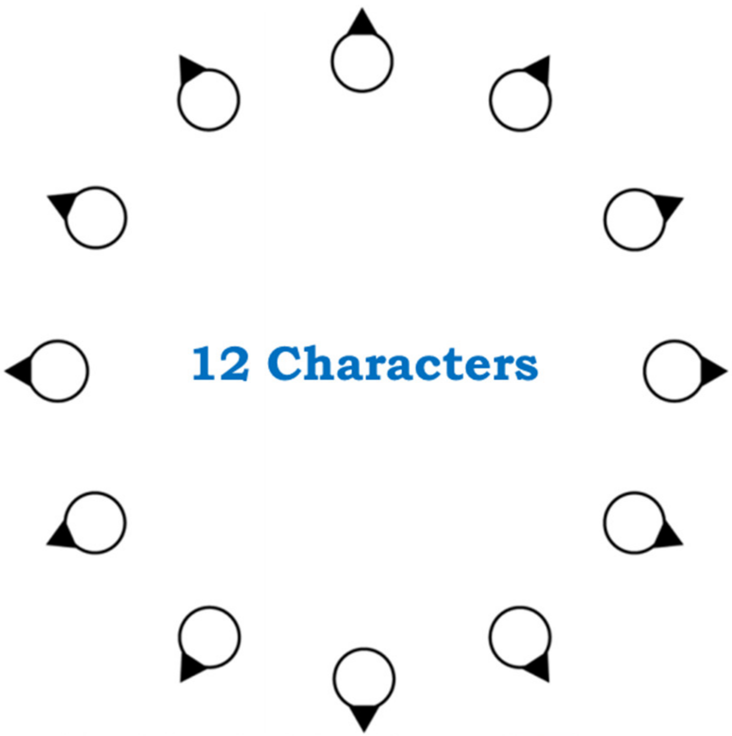
V or "Finger Four"



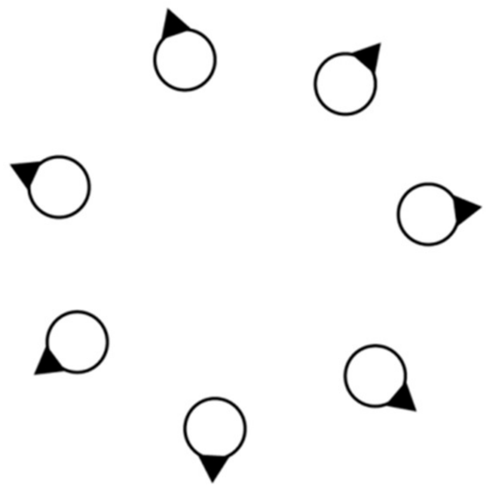
Two abreast in cover

# Scalable Formations

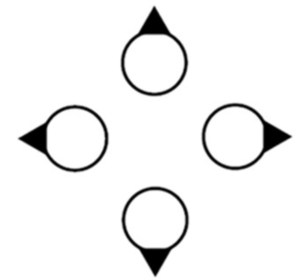
- The exact structure of a formation will depend on the number of characters participating in it.



12 Characters



7 Characters



4 Characters

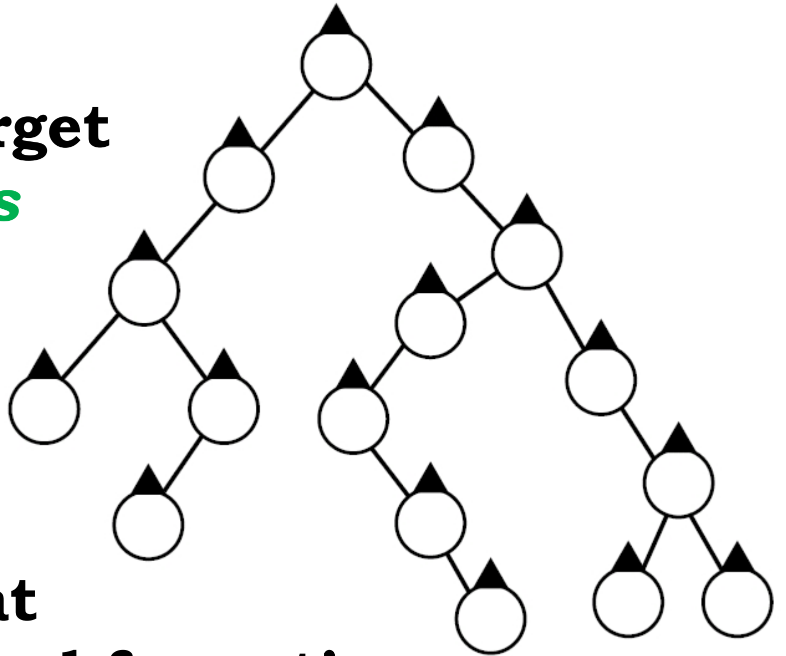
**Dynamically computed slot locations**

[http://www.moddb.com/mods/rearm/videos](http://www.moddb.com/mods/rearm/videos)

**With 100 defenders, it may be *possible to structure the formation in several concentric rings***

# Emergent Formations

- Emergent Formations (different solution to scalability)
  - Each character has its <u>own steering system</u>
    - Arrive Behavior
  - Characters select their target *based on other characters in group*
    - Allows characters to *<u>avoid obstacles individually</u>*
    - *Difficult to get rules* that do not lead to pathological formations
  - <u>May not have a leader</u>

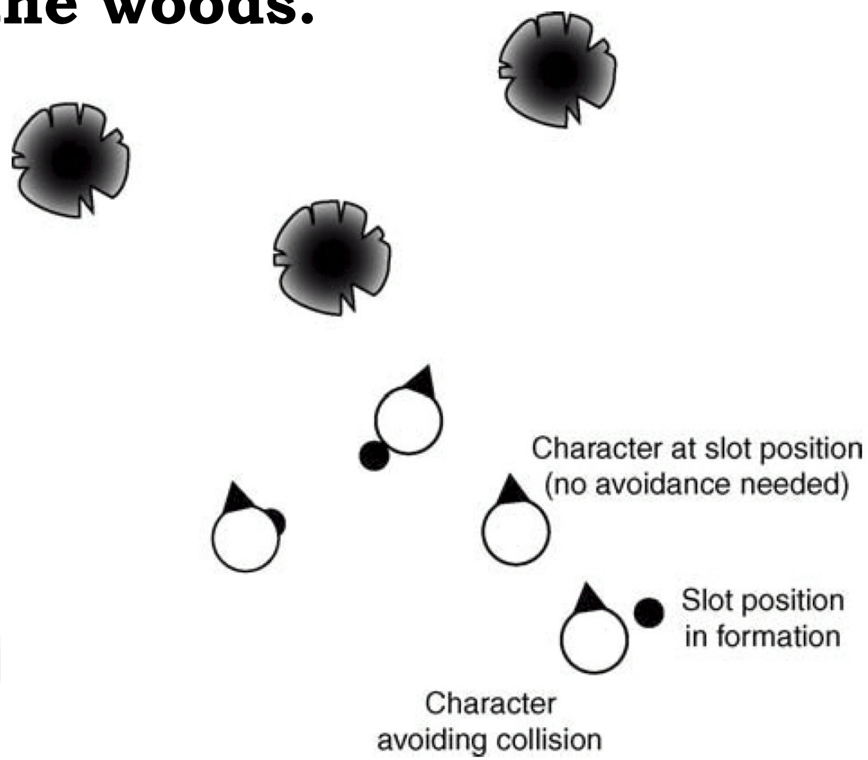


# Two-Level Formation Steering

- Combines ***strict geometric formations*** with the ***flexibility of an emergent approach***
- Use a strict formation, as before
- Initially, have a character that serves as *formation leader* (formation moves and turns with leader)
- Individual characters use emergent approach to steer individually
  - Use *arrival*, *avoidance*, and *separation* behavior to reach target slot (based on strict formation)
- Has difficulties when (*non-leader*) characters *run into obstacles* and cannot keep up with group

# Two-Level Formation Steering

- E.g., a number of NPCs moving in V formation through the woods.



# Two-Level Formation Steering

- In the example above, ***if the leader needs to move sideways*** to avoid a tree, then **all the slots/ characters in the formation will also lurch sideways**
- Instead: use a ***pseudo-character with a fixed location***. Its position will be the **pattern's anchor point** - used to lay out the formation pattern, slot locations, and formation rotation.
- A separate steering system will move the anchor point which is ***impervious to obstacles***, ***etc.***, but ***aware of large obstacles*** such as walls.
- All characters then react in the same way to their slots.

# Two-Level Formation Steering

- Thus far, information has only flowed ***from the formation to the characters***.
- If some characters are having problems keeping up, say, manoeuvring around the small obstacles ignored by the anchor point, ***the formation will be oblivious***.
- To **prevent problems** for characters keeping up:
  A. **Slow the formation down** (about half of character speed), or
  B. **Moderate movement of formation** based on current positions of characters in slot

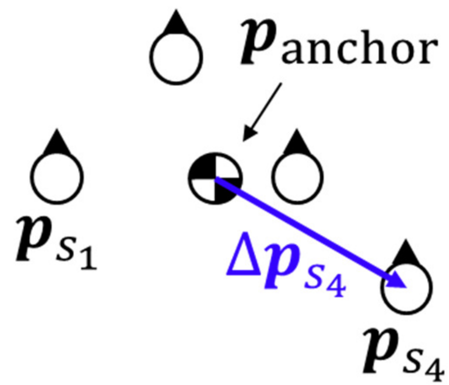
# Two-Level Formation Steering

- Latter approach: ***reset kinematics of anchor point***
  - Base the position, orientation, velocity of anchor points on the ***average position***, $p_c$ , and ***average velocity***, $v_c$ , of the characters in the slots
- Choosing exactly the average means that **characters are almost in position**, so that ***they move slowly*** towards their slot position.
- Anchor point moves ***even slower***, *etc*.
- Move anchor point ahead of the average position for moving formations:

$$p_{\text{anchor}} = p_c + k_{\text{offset}} v_c$$

# Two-Level Formation Steering

- Each character is assigned a slot coordinate $p_{si}$ that will be its target position for its individual Arrive behaviour.




- Each slot coordinate *w.r.t.* the anchor point (assuming default orientation) is

$$\Delta p_{si} = p_{si} - p_{\mathrm{anchor}}$$

- This <u>*does not change*</u> unless *different combinations of slots are occupied*, or a *character may be killed off* (changing $p_c$)
- Then the slot coordinate is $p_{si} = p_{\mathrm{anchor}} + \Delta p_{si}$
- This position is rotated around $p_{\mathrm{anchor}}$ by the <u>*formation orientation*</u>.

# Two-Level Formation Steering

- If the formation is to stop, we could ***set anchor point to average position*** for stationary formations:

$$p_{\text{anchor}} = p_c$$

- The slots will then be updated which will then ***move the anchor point***, causing the whole formation to **drift**.
- To correct this drift, the anchor point is set to the ***average position of the occupied slots*** (rather than the positions of the characters).
- Also, ensure that anchor point ***orientation*** is **average orientation of slots**, or ***formation will spin around***.

Université Concordia University

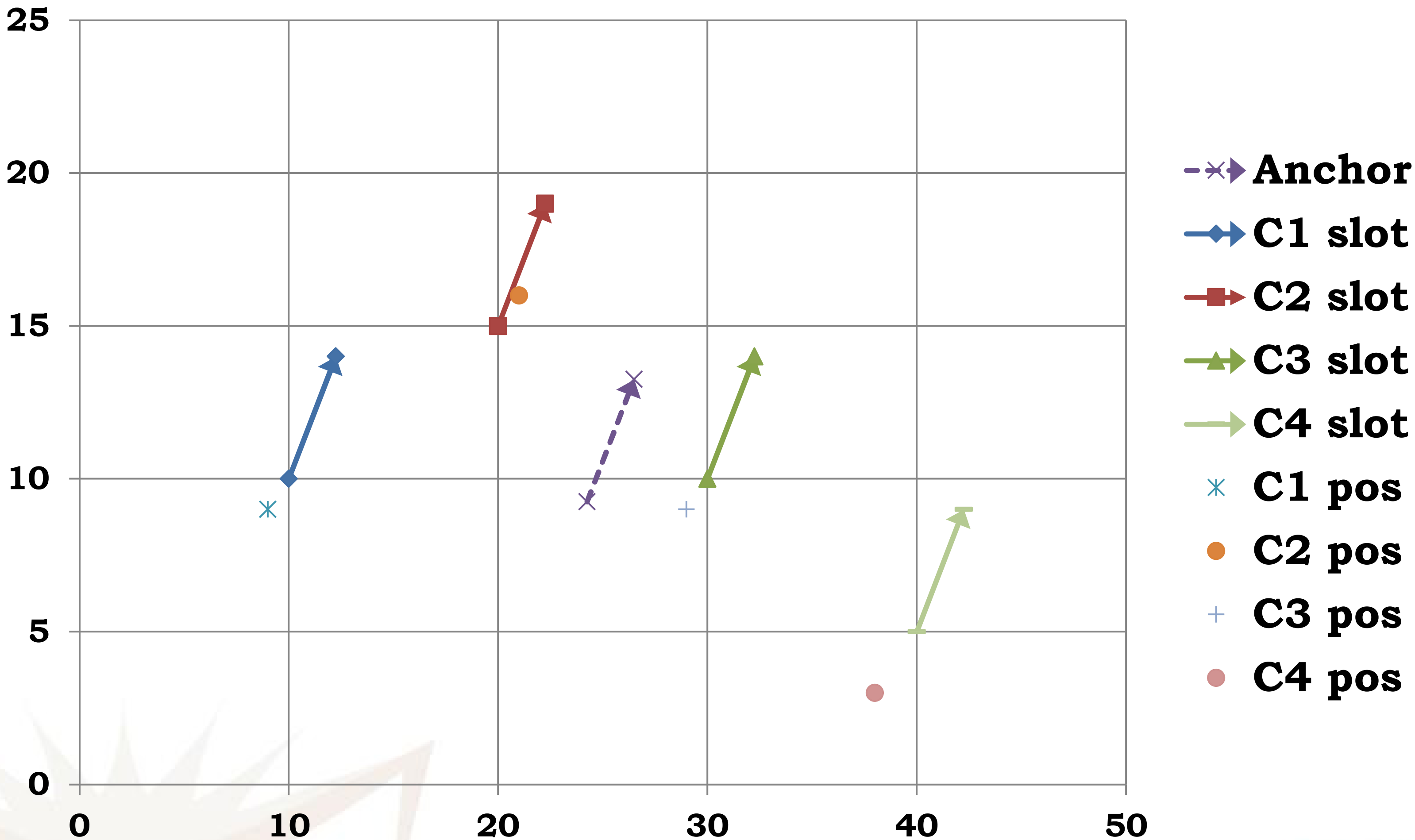
# Example

- Consider a ***V formation of four characters*** with a center of mass (or the current update's anchor position if no characters are lagging) of $p_c$ = (24.25, 9.25) and an average velocity of $v_c$ = (2.25, 4), so that the next update's anchor position (using $k_{\text{offset}}$ = 1) is $p_{\text{anchor}}$ = (26.5, 13.25).
- Consider character 1 whose slot position relative to the center of mass is $\Delta p_{s_1}$ = (−14.25, 0.75) . It's next slot position (used as the target position for that character's Arrive behaviour) is

$$p_{\text{anchor}} + \Delta p_{s_1} = (26.5, 13.25) + (-14.25, 0.75)$$

$$=(12.24, 14)$$

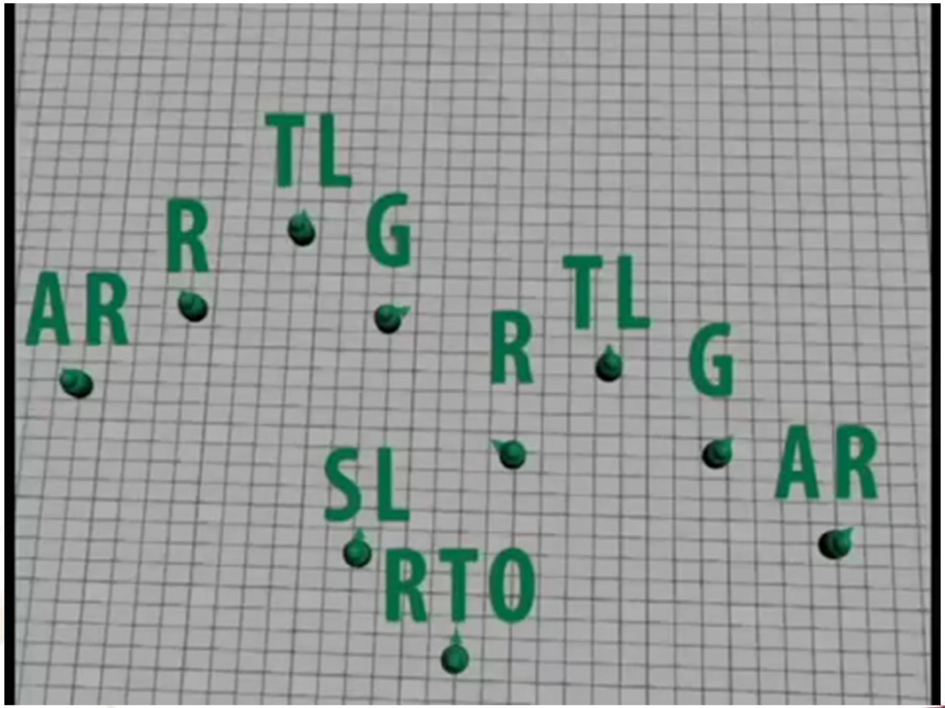
# Example



25
20
15
10
5
0
0
10
20
30
40
50
Anchor
C1 slot
C2 slot
C3 slot
C4 slot
C1 pos
C2 pos
C3 pos
C4 pos

# Extending to More than Two Levels

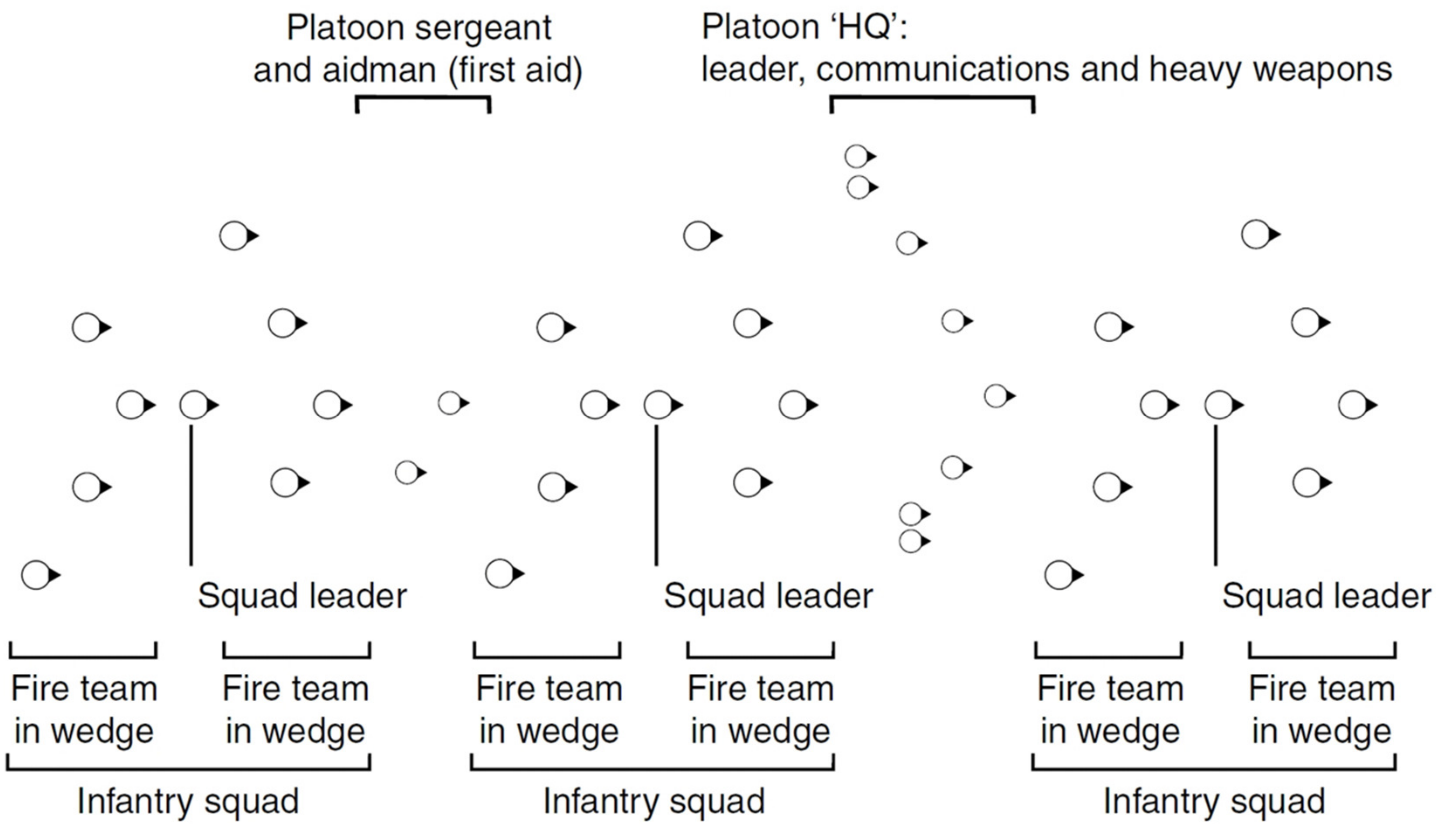
- The two-level steering system ***can be extended to more levels***



# Extending to More than Two Levels

- Needed for *military simulation games with lots of units*
  - Consult *public military manuals* how to organize a platoon in different squads
- Slot positions now distinguish between roles of characters:
  - E.g. *Fire teams*, *squad leader*, communication, *platoon leader*, heavy weapons team, …

# Nesting Formations to Greater Depth

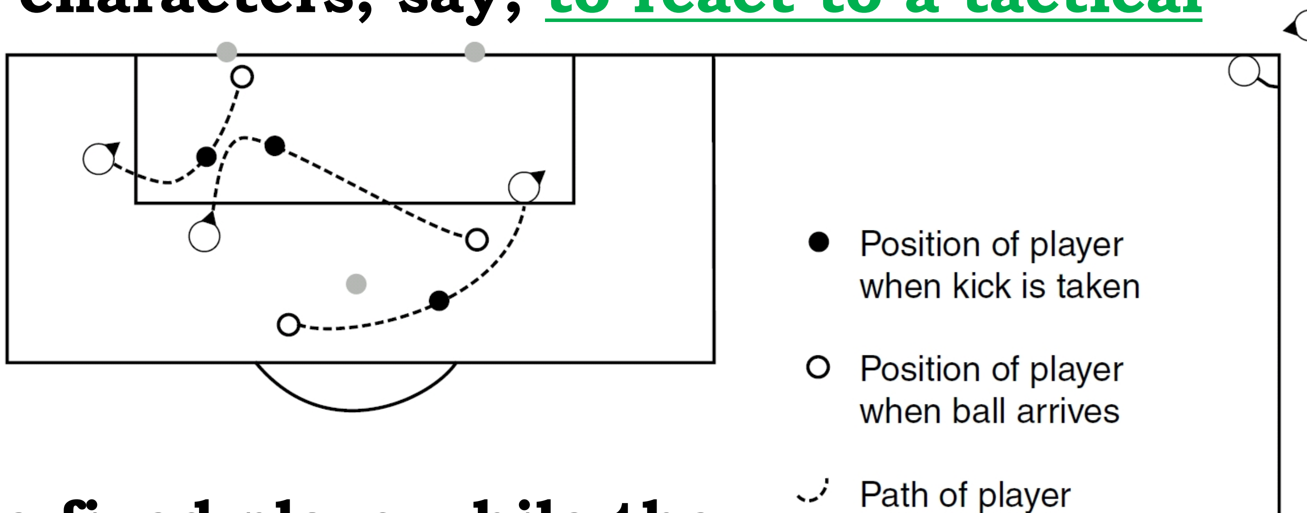


# Dynamic Formation Patterns

- **Dynamic slots and playbooks**
  - **Not all games can use constant formations**
  - **Slots can be *dynamic*, *moving relative to the anchor point of the formation***
    - **E.g. Fielders in a textbook baseball double play**
    - **E.g. Corner kick strategies in soccer**
    - **E.g. The basis of tactical movement**
- **Characters can "jump" to their new locations using Arrive behaviour to move there.**
- **An element of time needs to be introduced.**

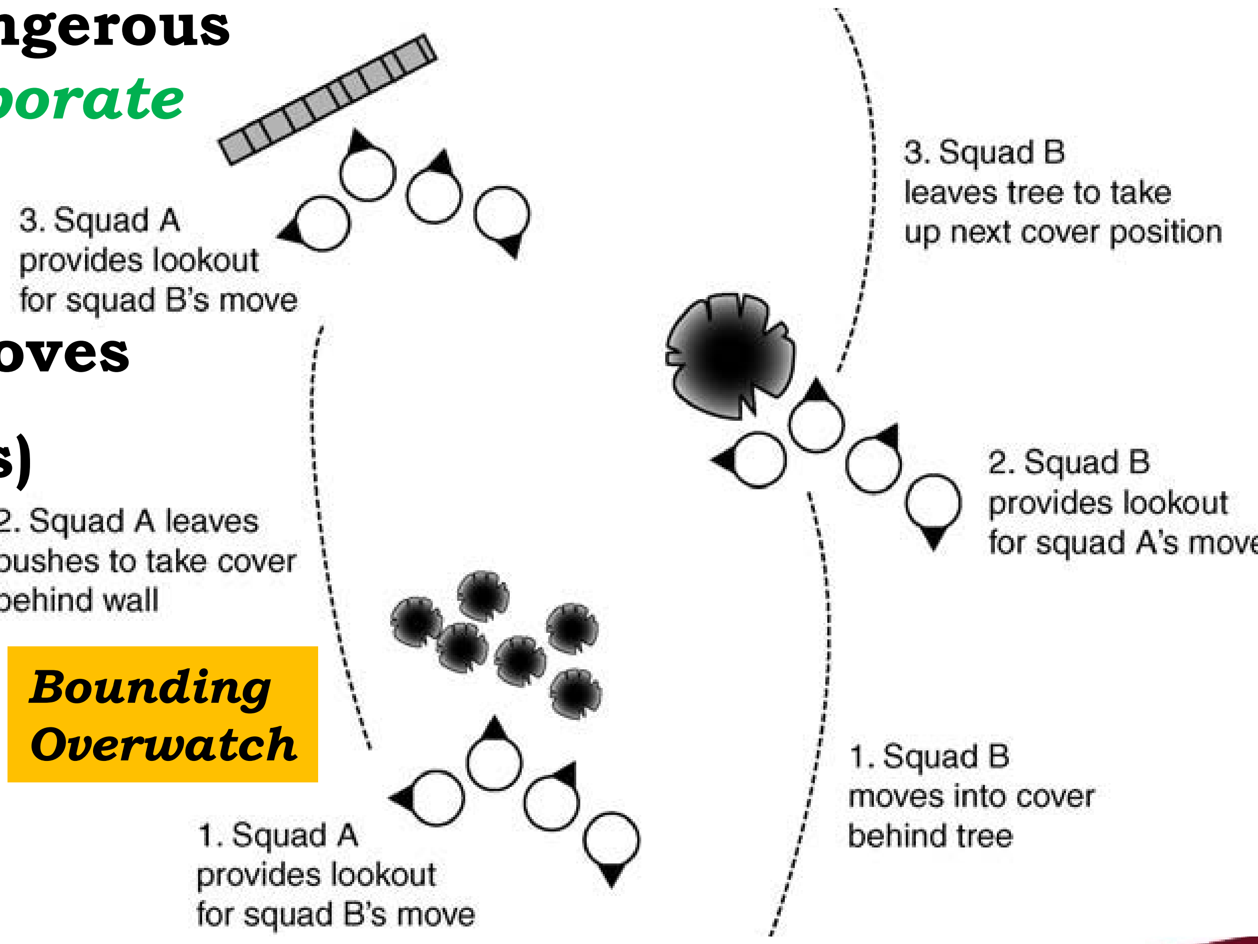
# Dynamic Formation Patterns

- The moving slot positions ***need not be completely pre-defined***. The slot movement itself can be determined dynamically by a controlling AI routine, moving the characters, say, **to react to a tactical situation**.
- In practice, **a mixture is used**. Below, three players have fixed plays while the ***others react*** ***to the defending team's players***.



# Tactical Movement

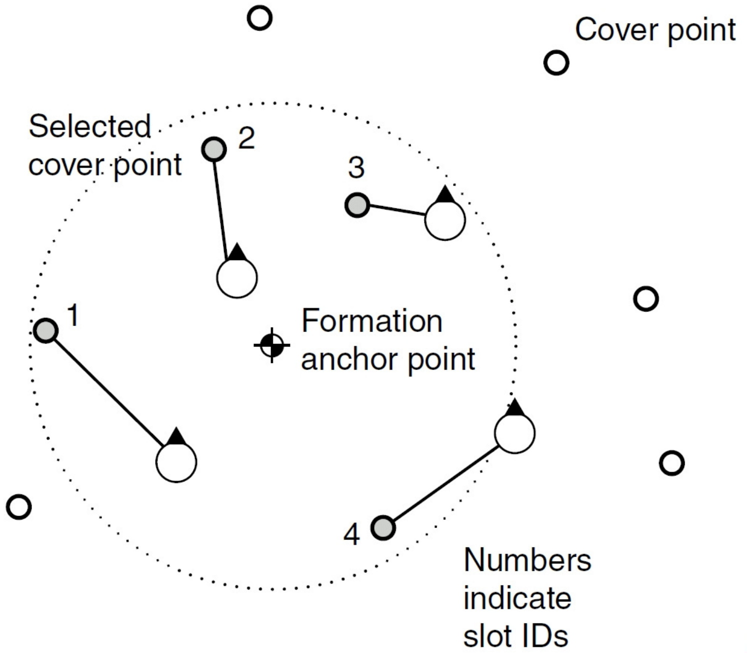
- **Squads in dangerous terrain *collaborate with other squads***
- **One squad moves**
- **Other squad(s) provide *lookout and fire cover***




***Bounding Overwatch***

# Squad-Based Movement

- Dynamic formation patterns can also be used to create ***a very simple but effective approximation of bounding overwatch***. The **formation slots** move between cover points (where a character is safe).
- The ***closest set of cover points*** to the anchor point is used.
- The **formation pattern** uses of this set for the location of each slot.
- The formation is now **linked to its environment**



# Squad-Based Movement

- As the formation moves, the [*set of cover points will change*]. When one cover point leaves, the slot assigned to it will now be assigned to [**the newly arriving cover point**].
- The [**anchor point**] should move slowly compared to ***the individual characters***
- Alternative anchor point: [**lead character**].