

“An ideal virtual camera system, regardless of genre, is notable by the *lack* of attention given to it by the viewer”

From Introduction to:
M. Haigh-Hutchinson,
Real-Time Cameras: A Guide for Game Designers and Developers,
Morgan Kaufmann 2009.

[available to WPI students free online via ScienceDirect:
<http://www.sciencedirect.com/science/book/9780123116345>]

Note: if you don't notice camera, then it is working well!

Show God of War clip (with sound off to minimize distraction). Pause at notable points.

Designing and Implementing a Dynamic Camera System

Phil Wilkins
Sony Playstation Entertainment
GDC '08
[edited by C. Rich]

Phil did camera work for God of War.

After this lecture you might want to change/add one of the camera-control techniques we discuss as a technical element in your game. Ok to do that.

Objectives

- Flexible
- Designer driven
- Smooth
- Not require player intervention
- No collision

No collision with the environment. By which I mean that it is up to the *designer* to constrain the camera such that it doesn't go through walls.

Whenever I've tried *automatically* resolving camera collision with the environment in the past, it's always introduced pops, or it gets hung up on geometry.

Collision geometry is designed to constrain the player, not the camera.

Overview

- Zoning
- Dynamics
- Blending
- Rails

Zoning deals with the use of a spatial database to *select* cameras,

Dynamics is the calculation of a single dynamic camera

Blending is where we *smooth out the transitions* between cameras

Rails deals with constraining the camera to a *path*

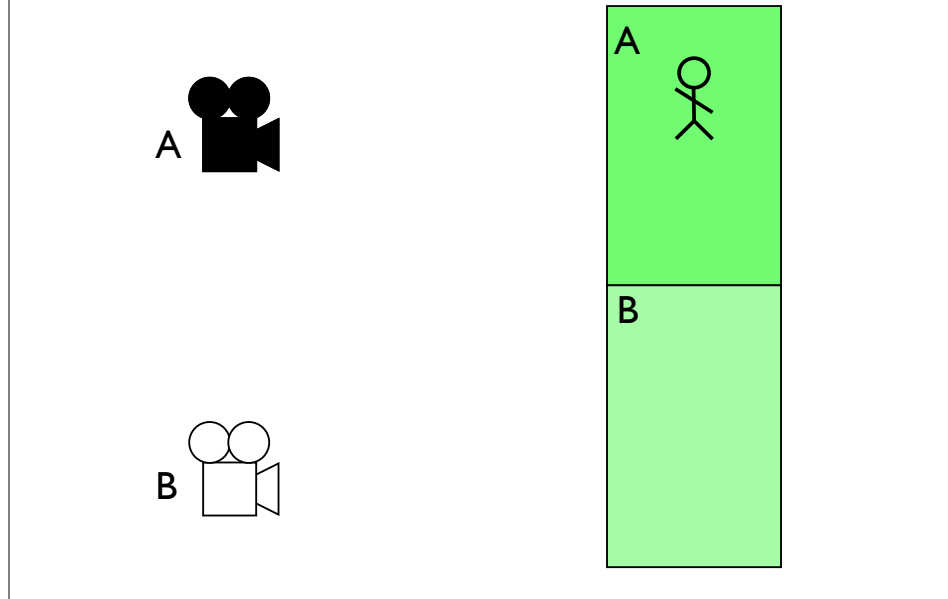
Overview

- Zoning
- Dynamics
- Blending
- Rails

Zoning : Objectives

- Stationary Cameras
- Chosen by Player Position

Zoning : Design

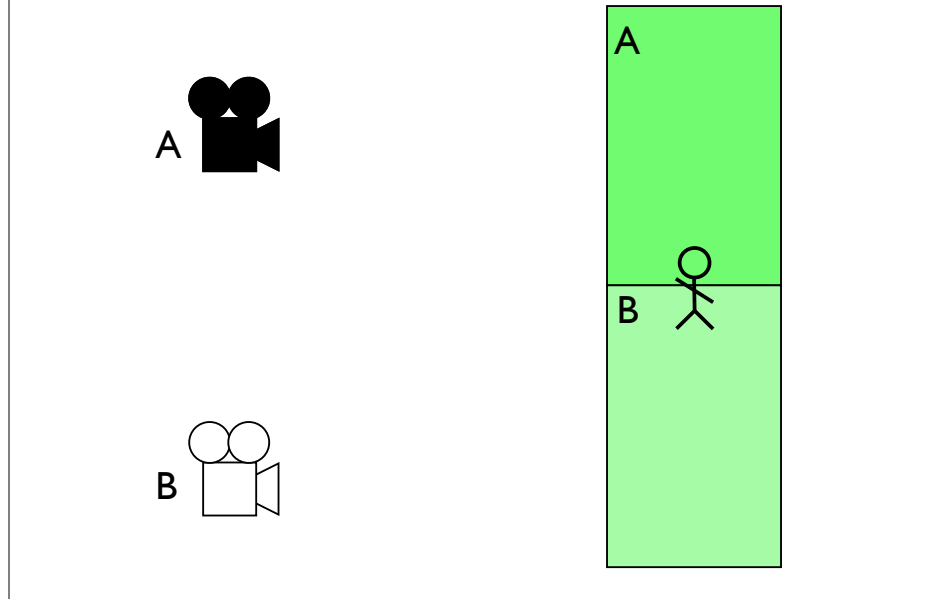


The game has a spatial database of *zones*.

Each zone references one or more cameras, although for the moment we'll just deal with the case where each zone references a single camera.

(Animate simple camera switch when player crosses from zone A to B.)

Zoning : Design

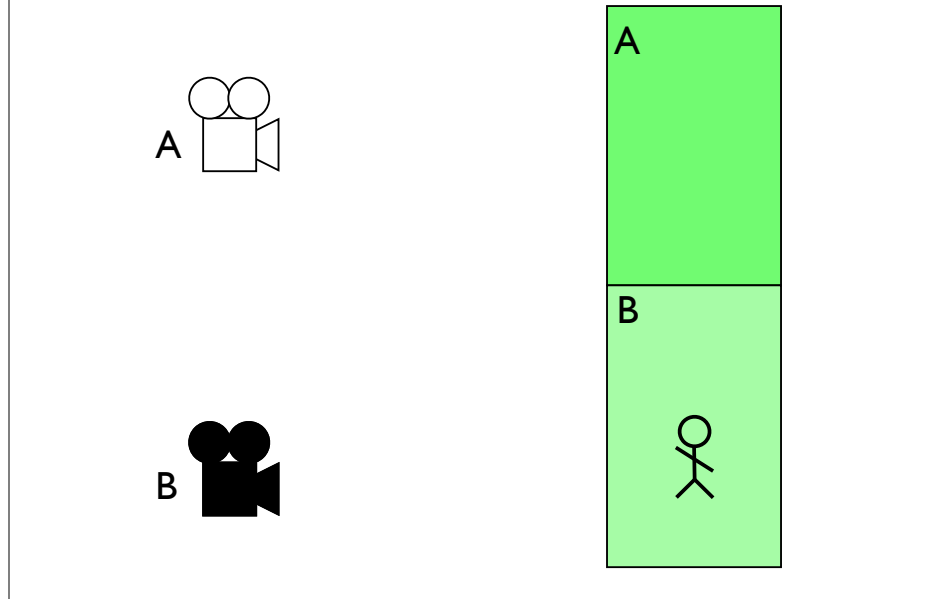


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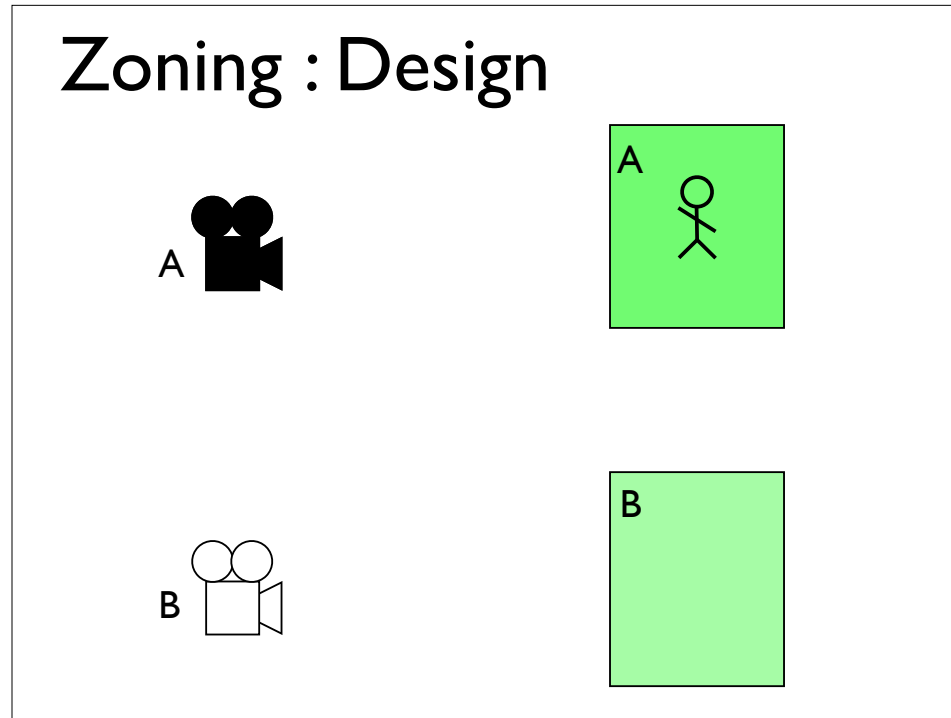


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Notice zones *do not touch* here.

When the player moves into a zone that references a camera that isn't the currently active one, we activate that camera.

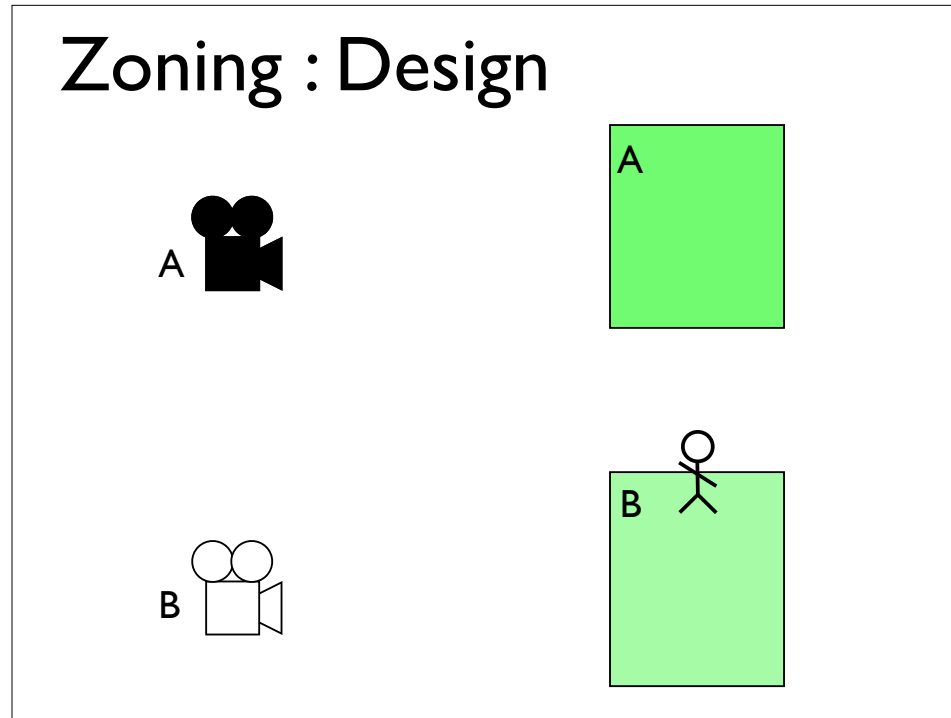
(Animate transition from A to B)

This allows us to loosen up the boundaries between cameras.

This also adds hysteresis (*stickiness--why?*) to our system, by playing with the boundaries of the zones.

(Animate transition from B back to A. Note that where the camera is during whitespace depends on which direction it was moving.)

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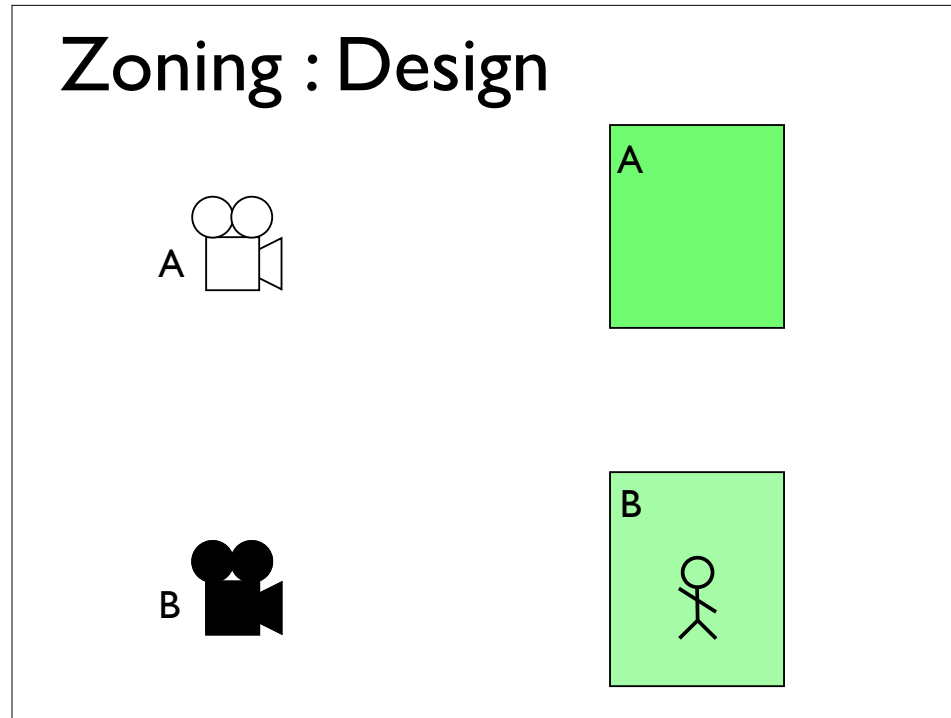
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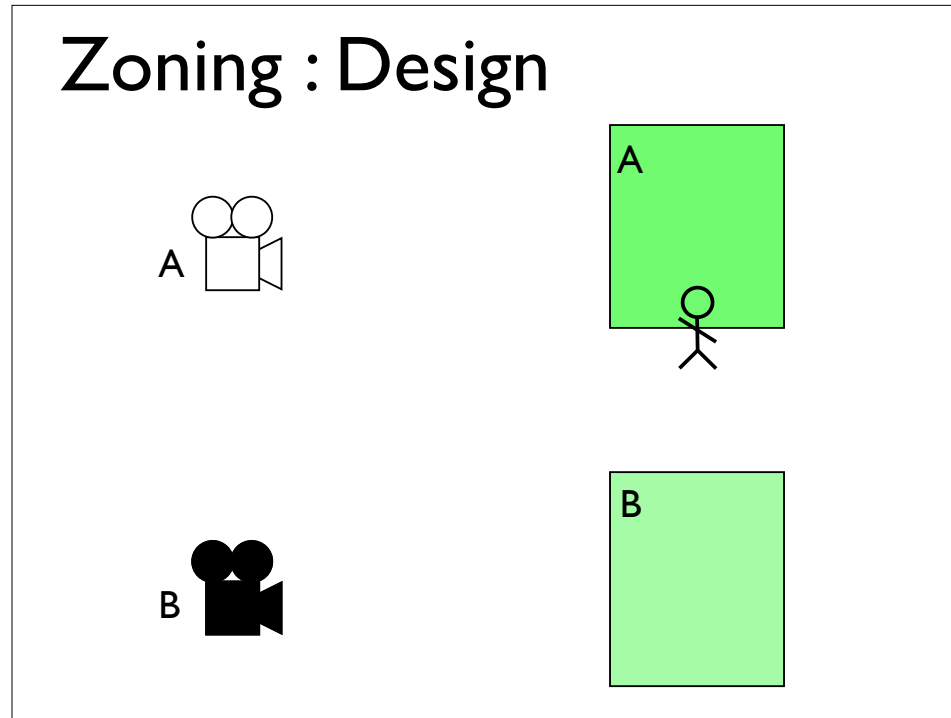
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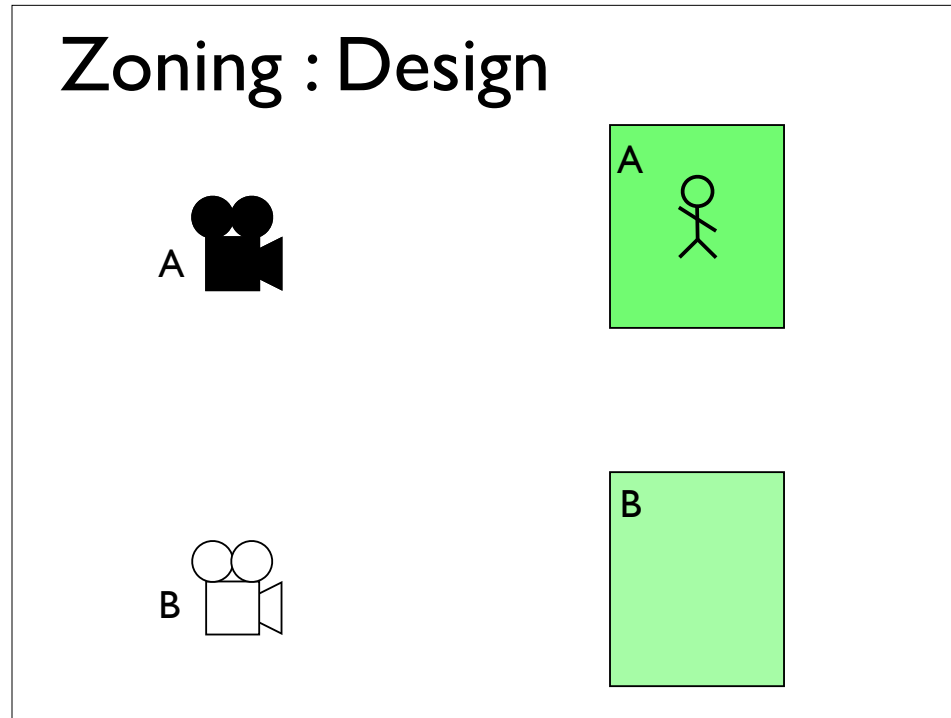
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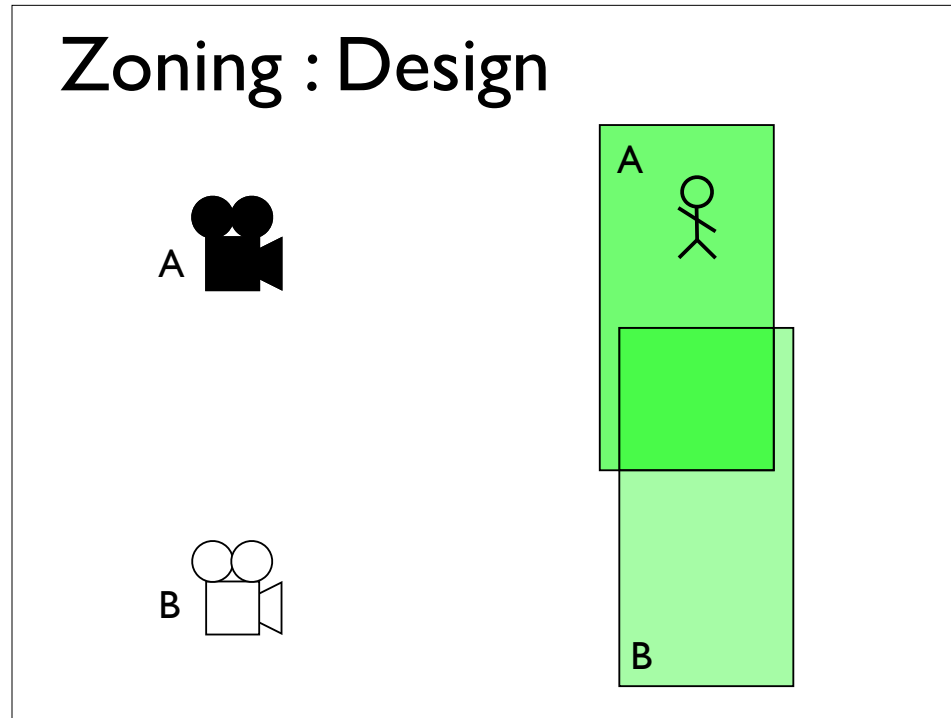
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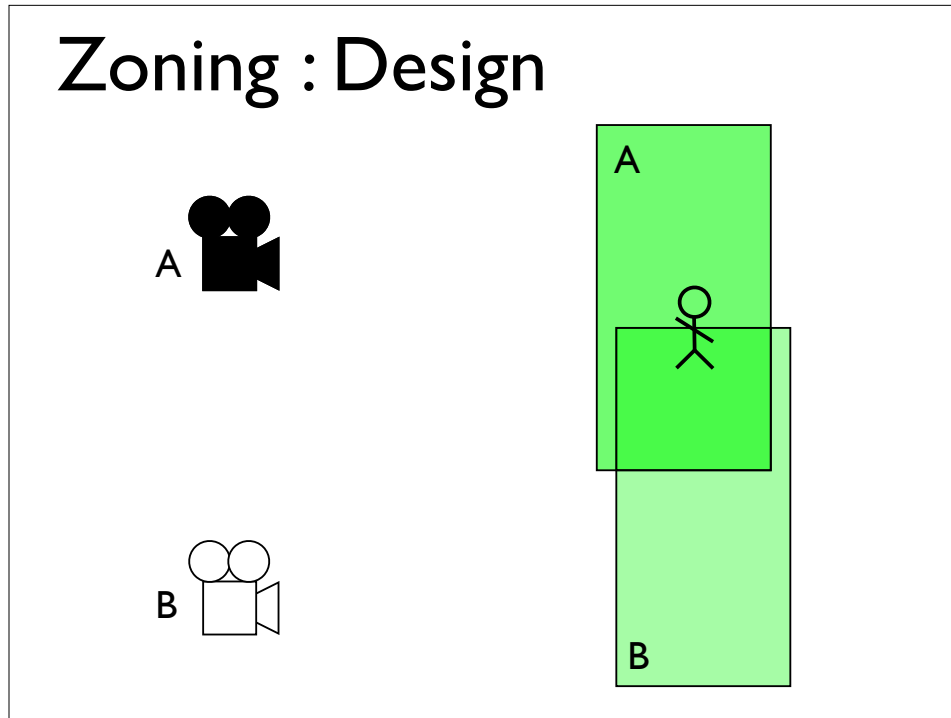


We can also *overlap* the zones.

In which case, when we enter the overlap space, we always change to the new camera.

(Animate from A to B and back again.)

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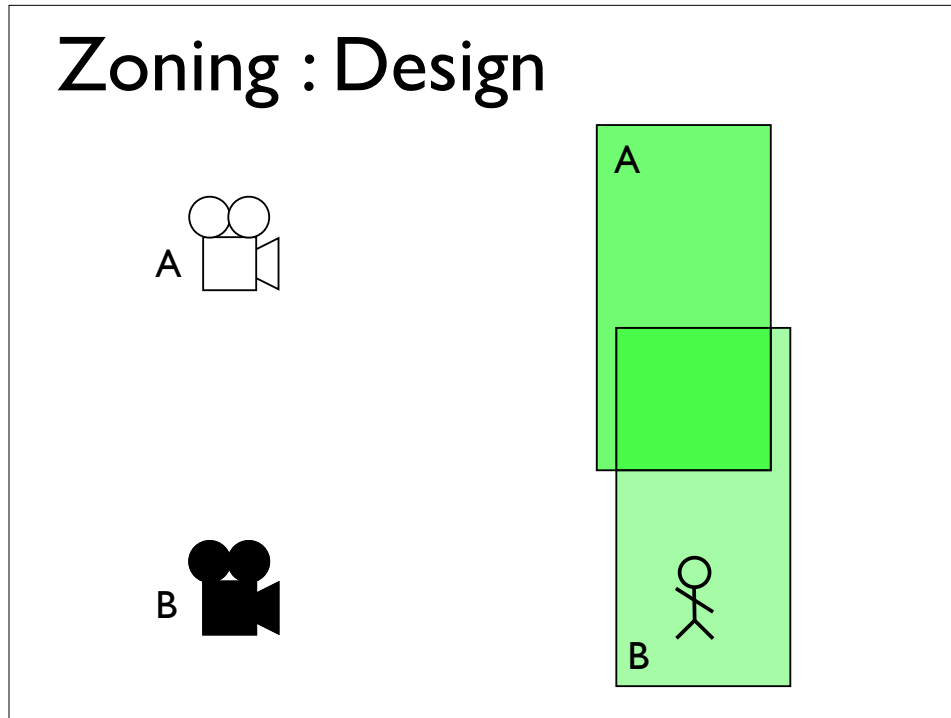


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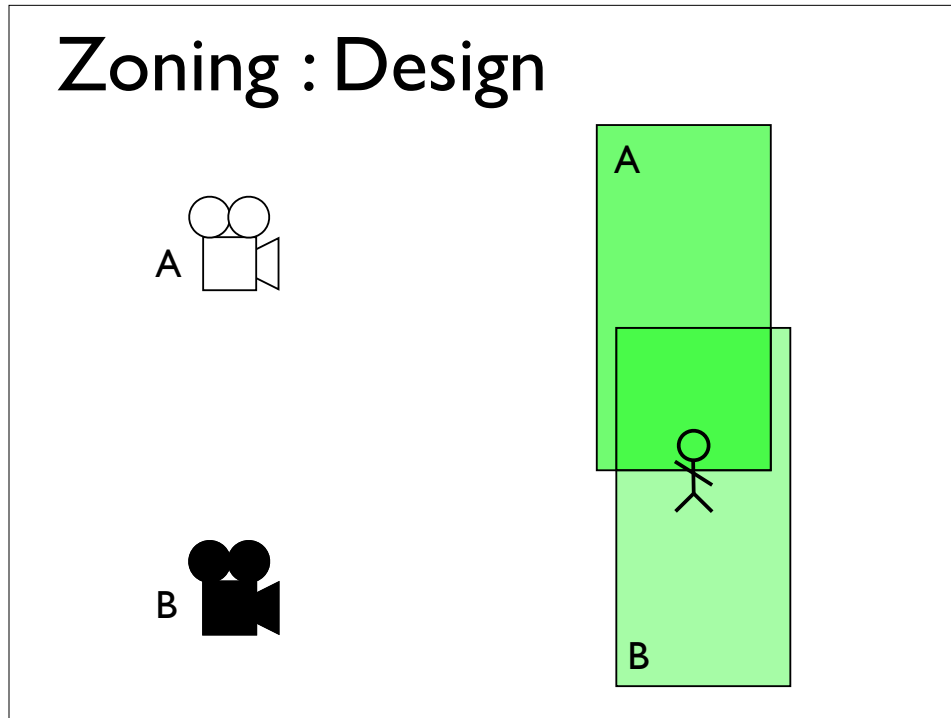


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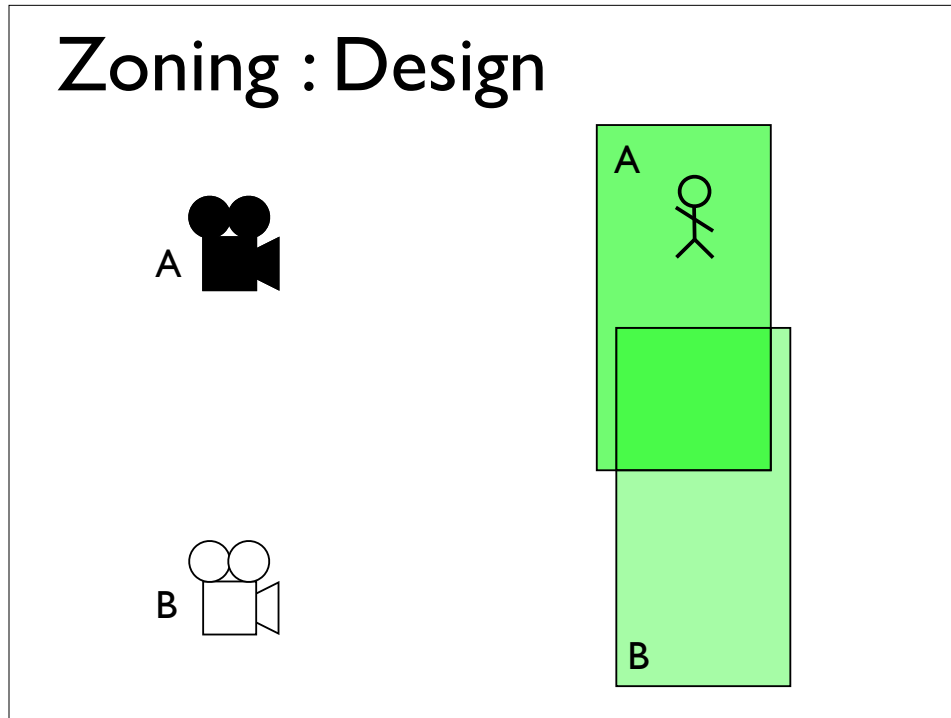


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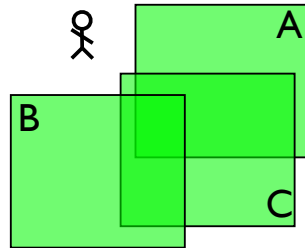


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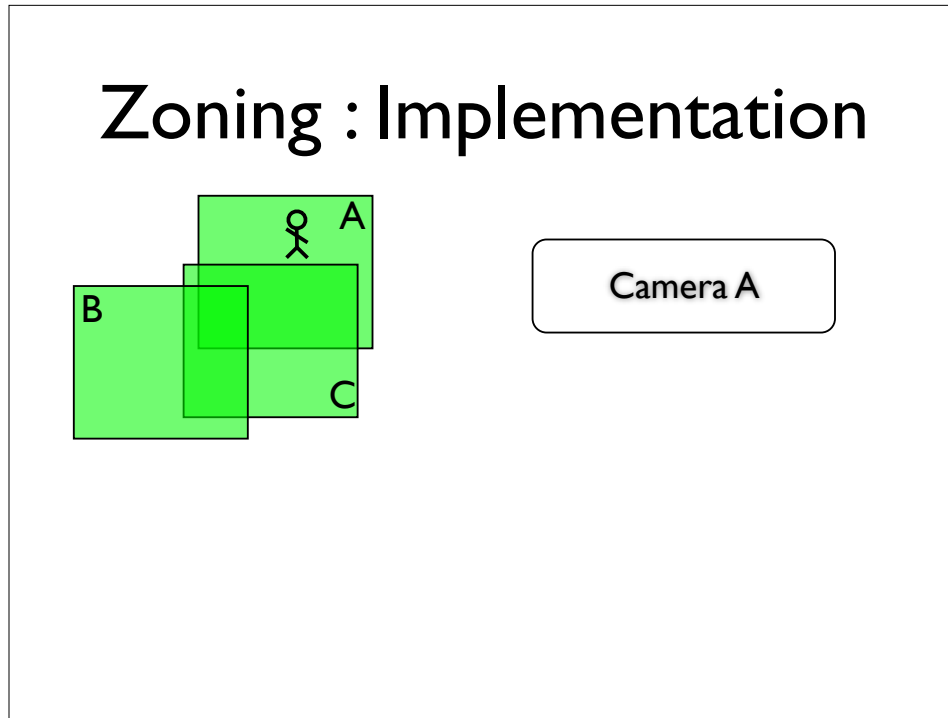


So, *in general*, at runtime, at each frame, we query the spatial database of zones for current player location and get back a *collection* of camera references.

Since we can't, or don't want to make too many assumptions about the zone database, we treat the results as essentially unordered.

(Animate example until left with just Camera B)

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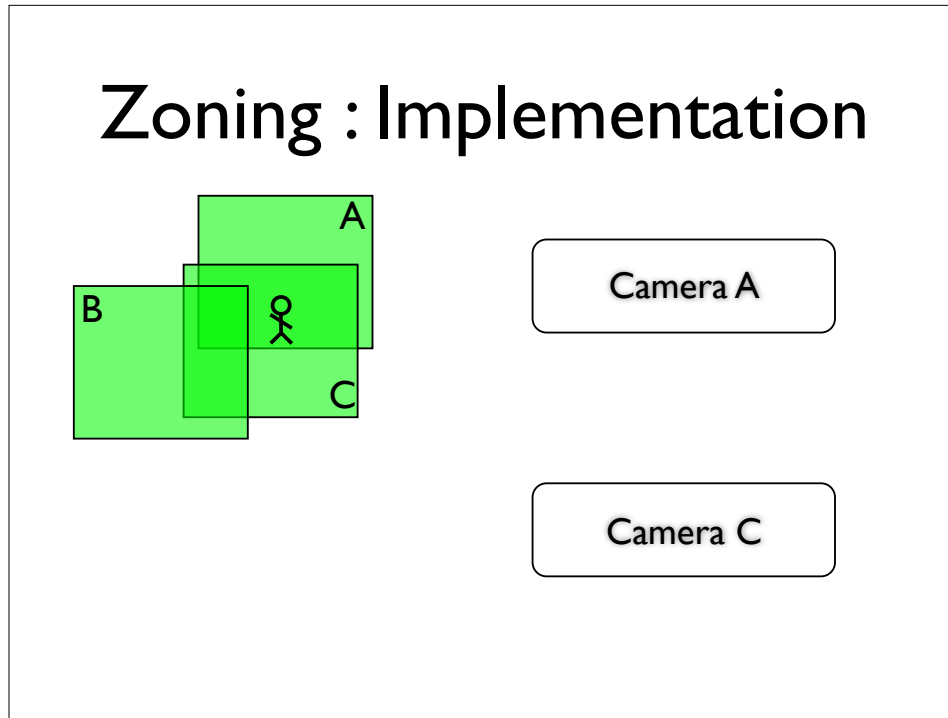


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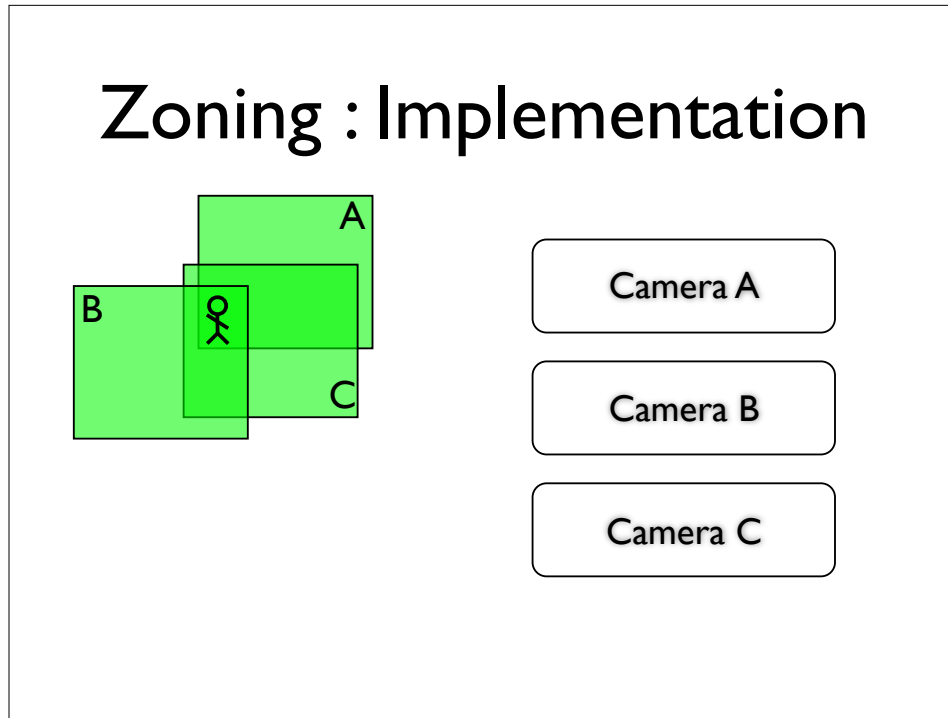


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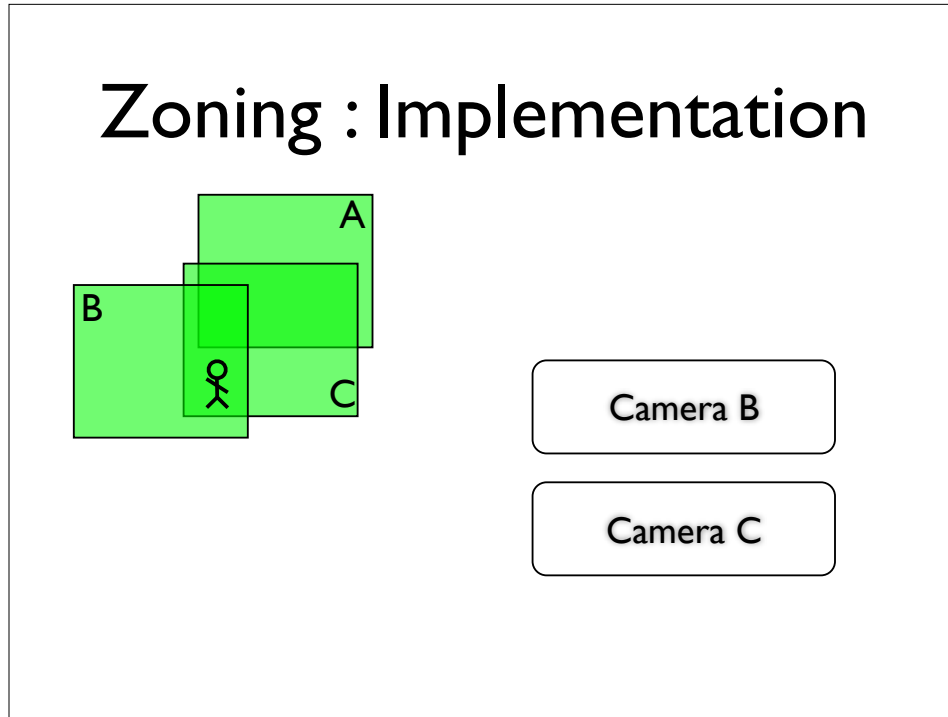


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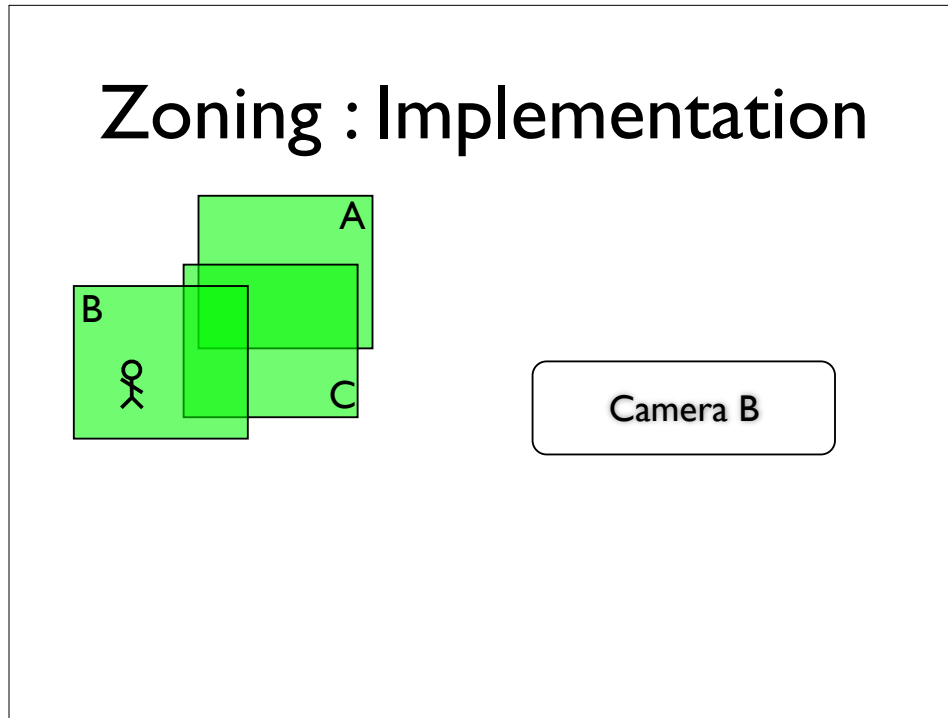


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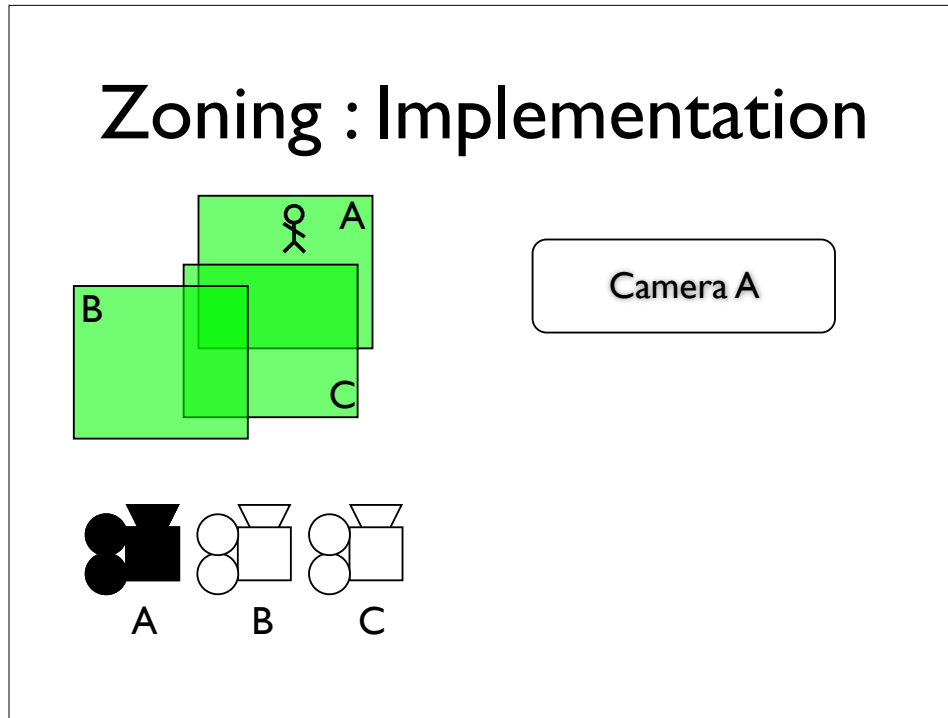


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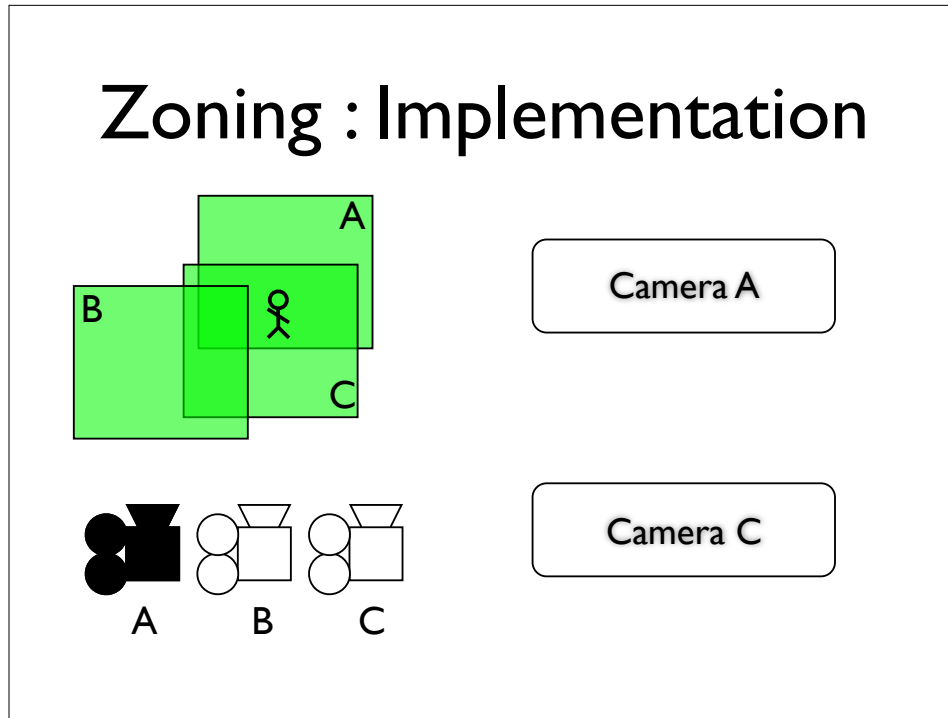


A naive implementation would just compare the results from the query, against the currently active camera, and if there's a difference, swap to the new camera. This works fine, *unless your zones overlap—i.e., there might be more than one camera. So what do we do?*

In this example, when we move from zone A into the overlap between zones A and C, we start off right, by switching to camera C,

but next frame, we're still in the overlap, still getting A and C back from the query, but now C is the active camera, and A looks like it's new, so we swap to A. Until next frame, when... well you get the idea, we're going to alternate between the two, which really isn't what we want.

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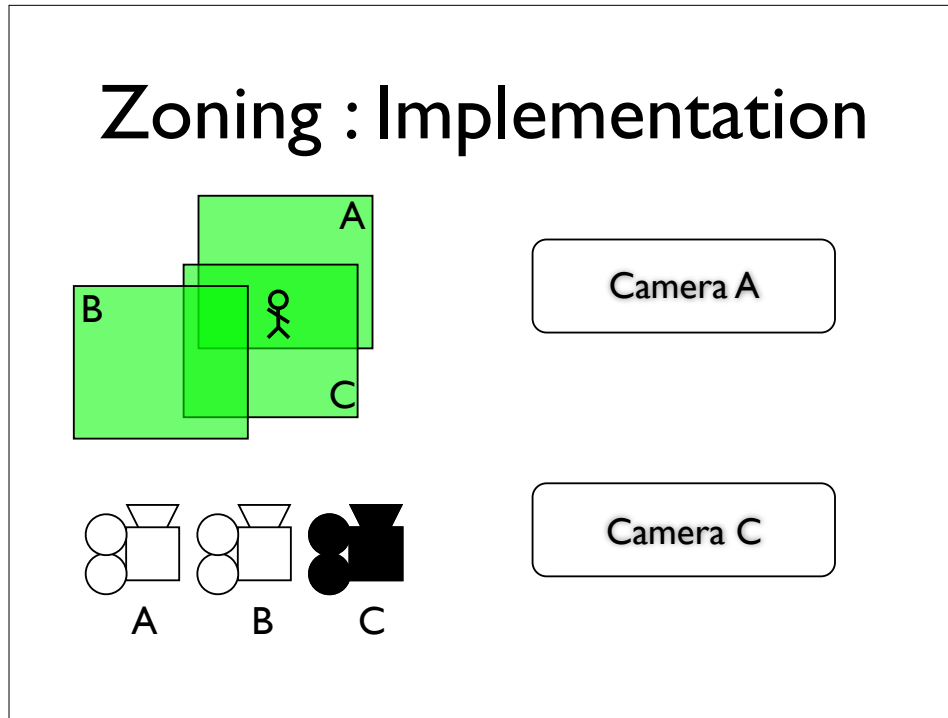


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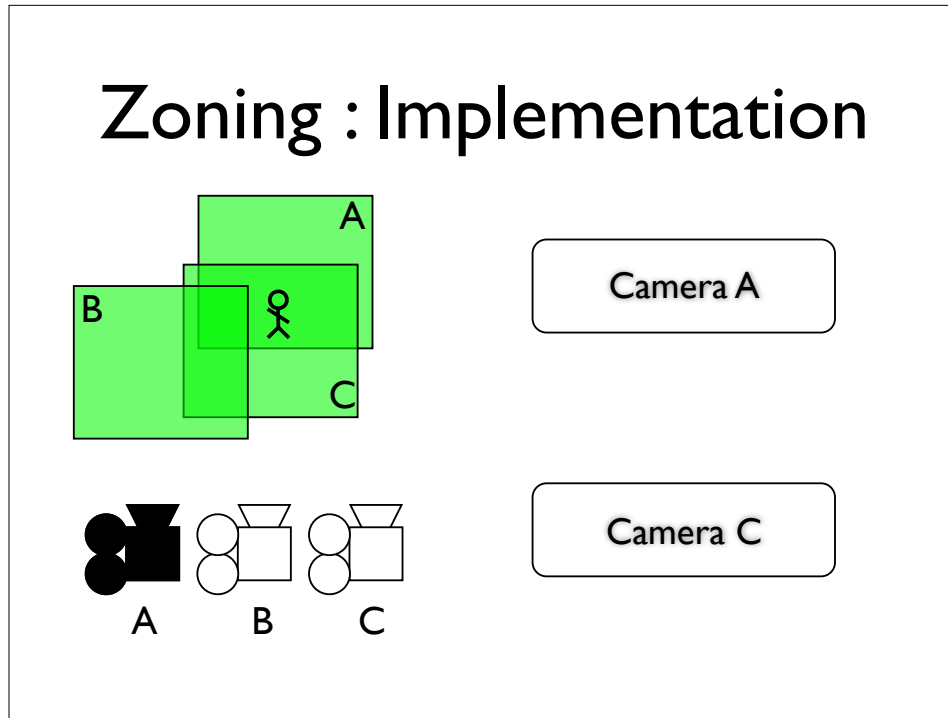


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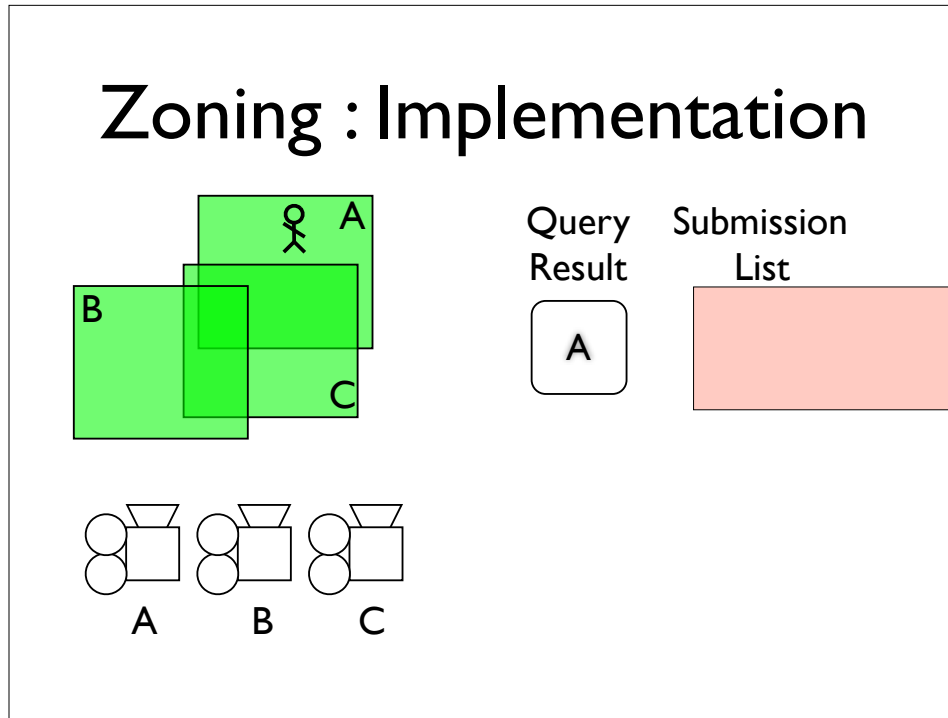
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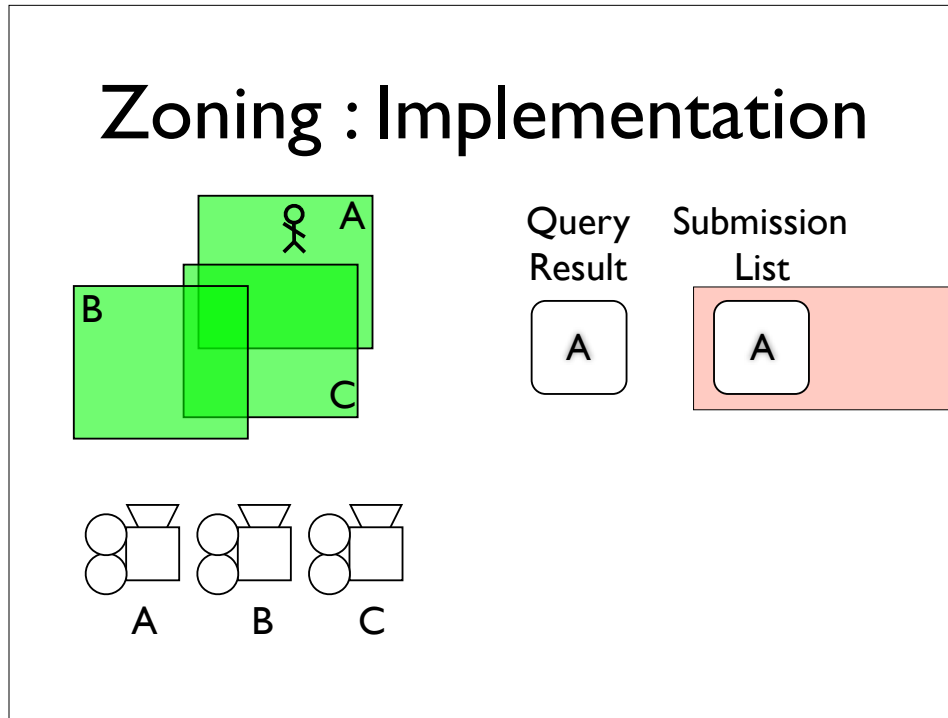
- Submission List
 - List of all cameras that were submitted last frame.
 - Used to distinguish newly submitted cameras from old ones
 - New cameras inserted at top
 - Effectively sorted by age

Zoning : Implementation



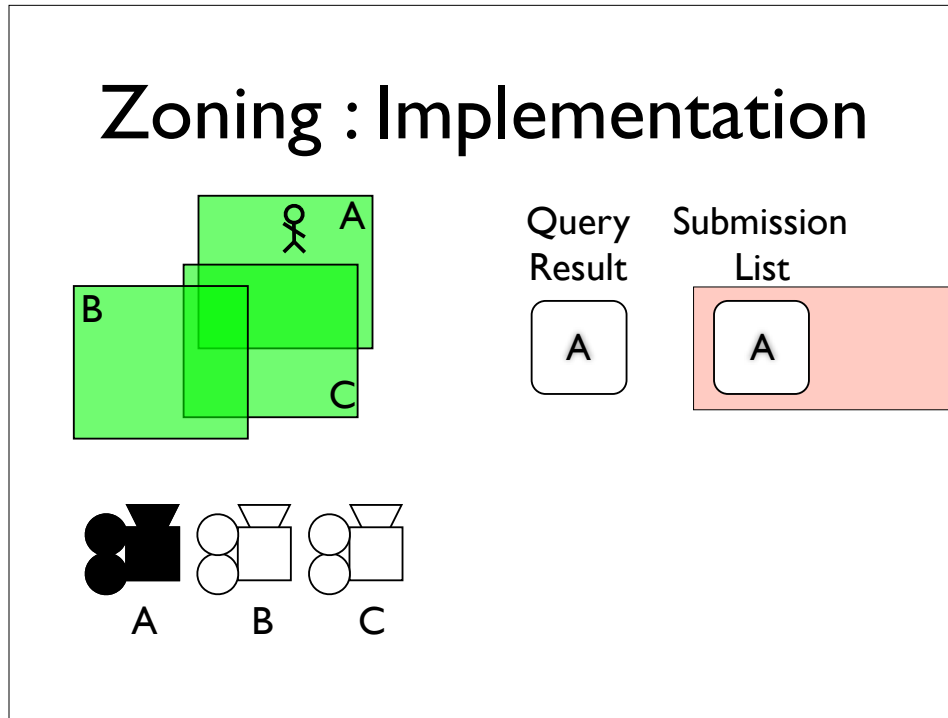
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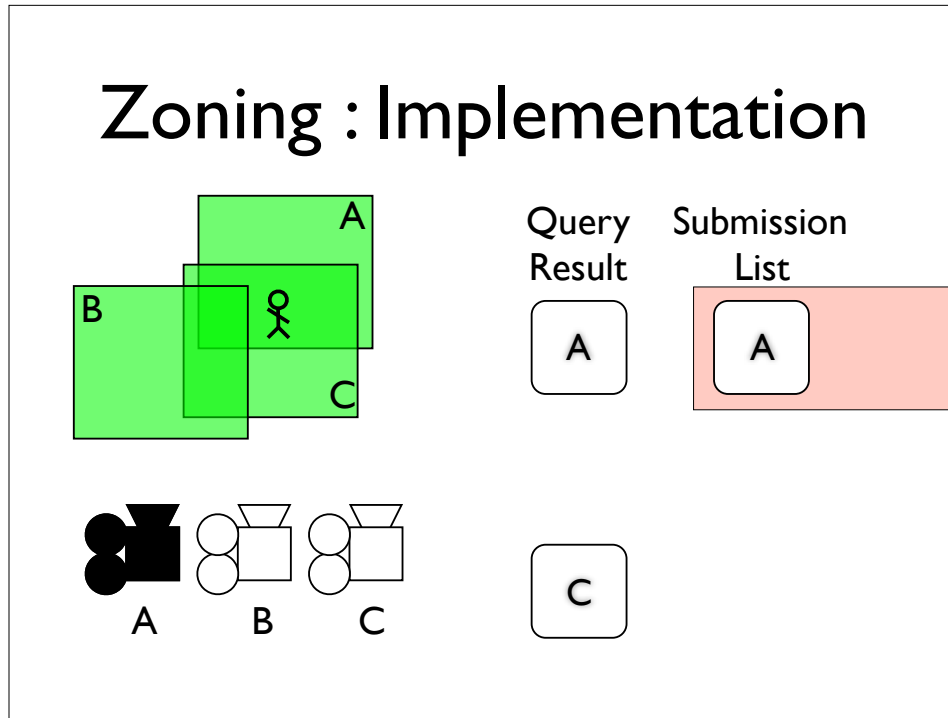
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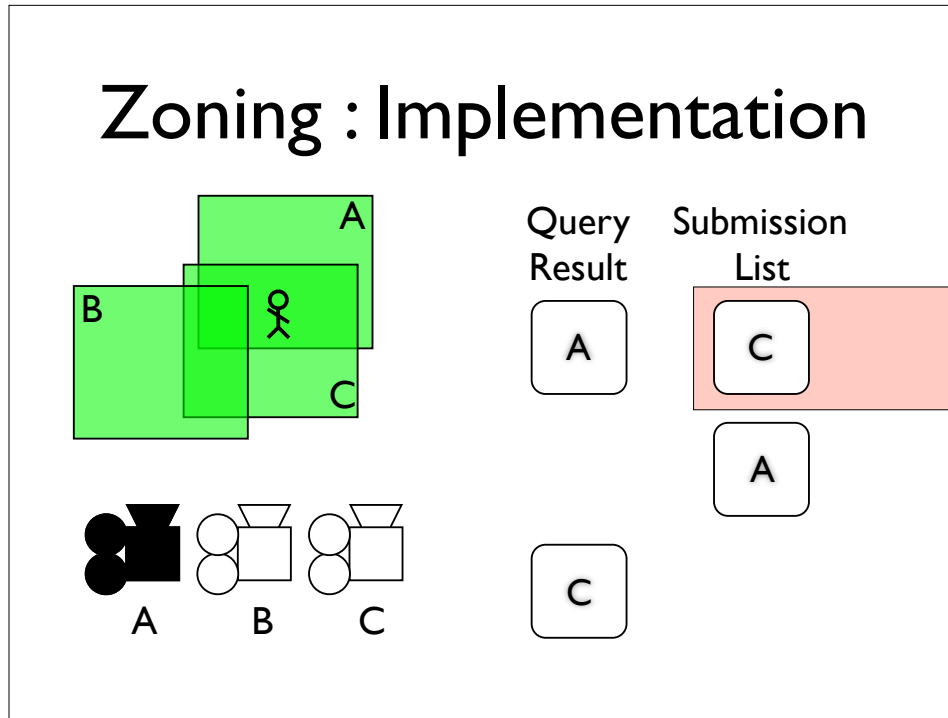
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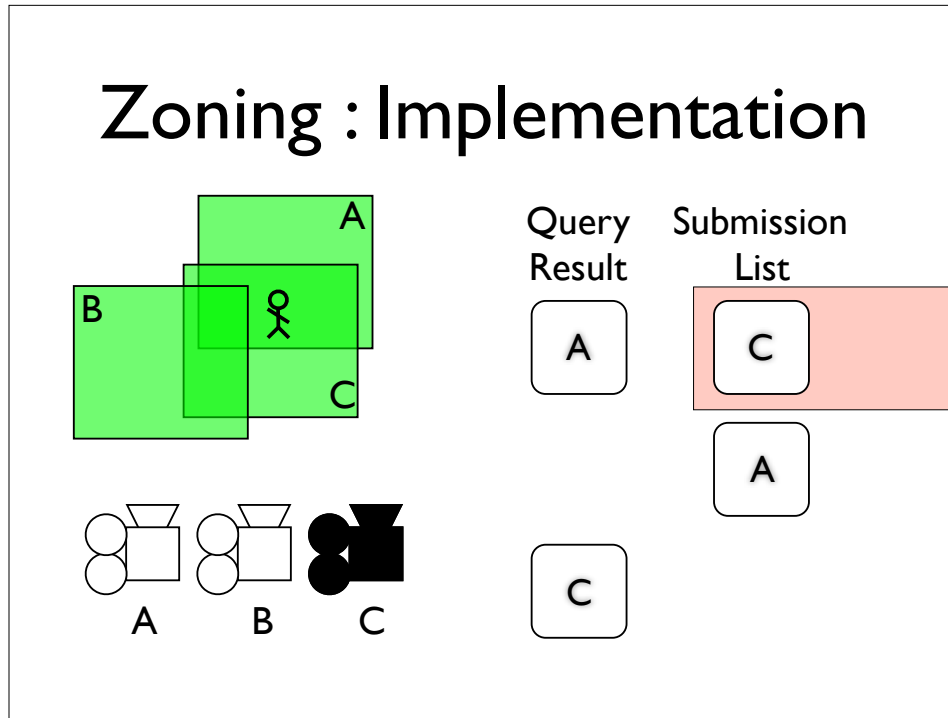
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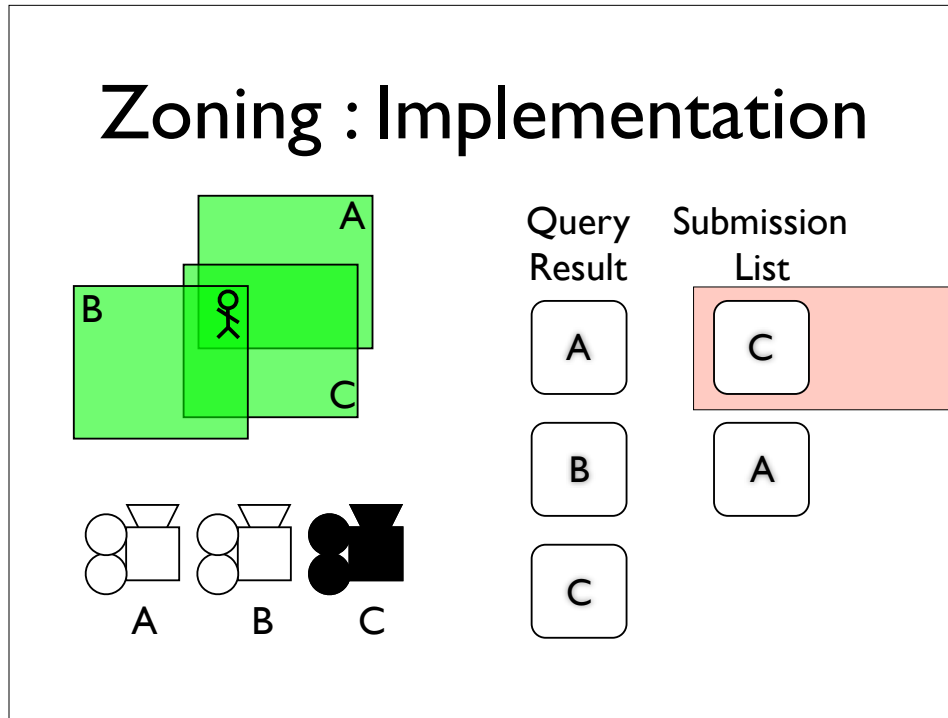
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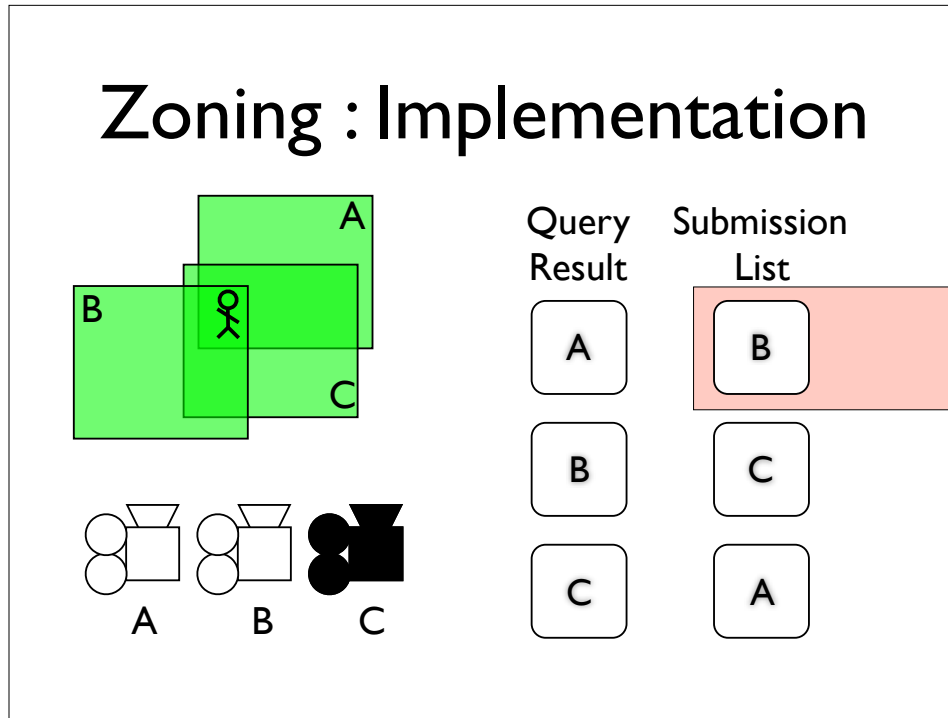
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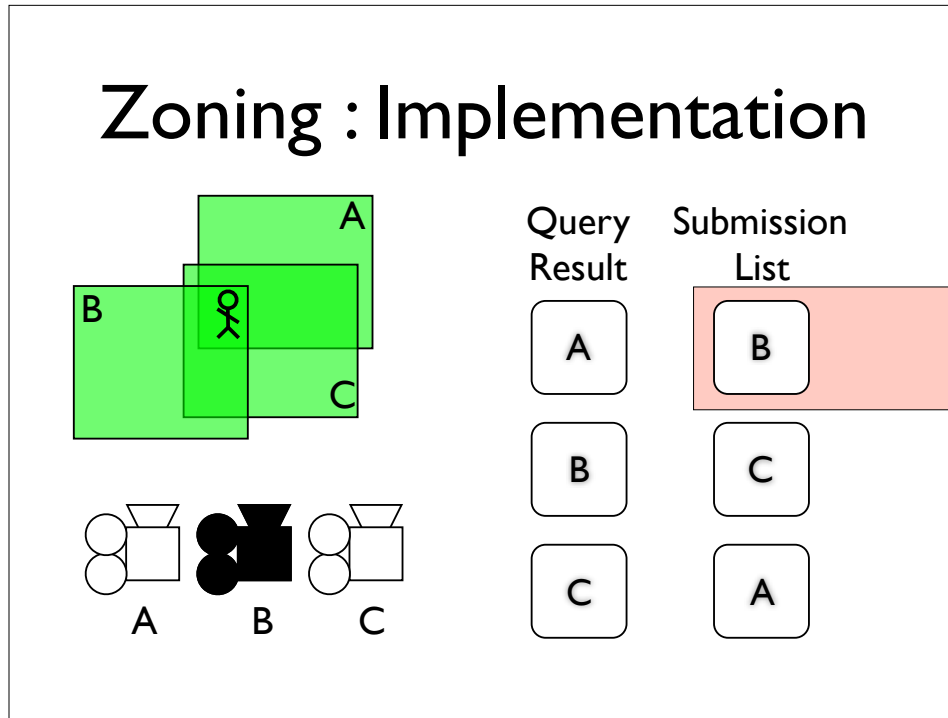
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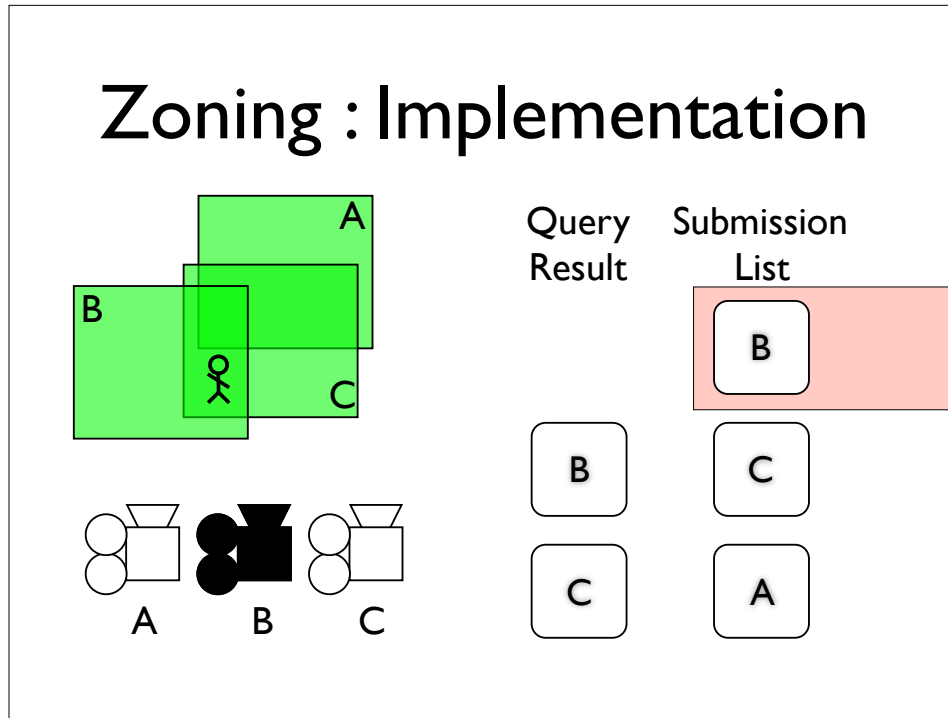
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Zoning : Implementation



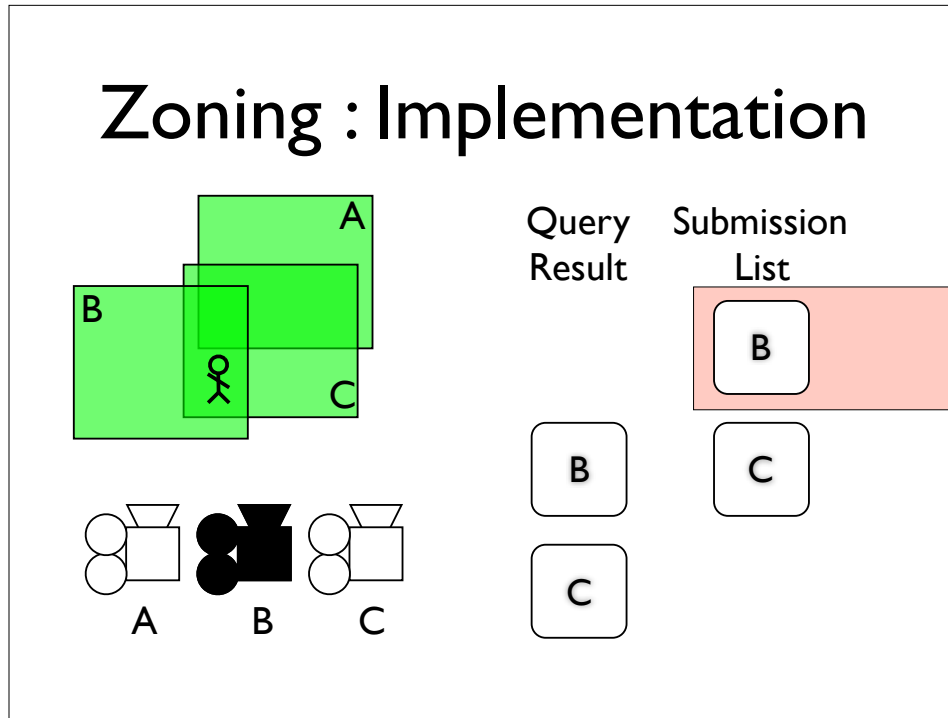
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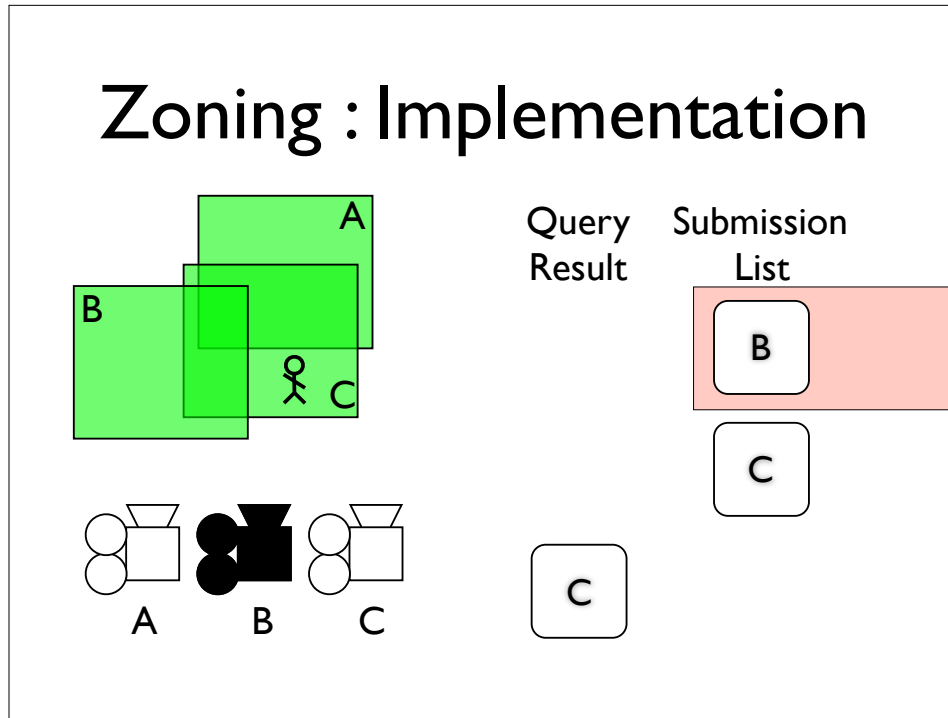
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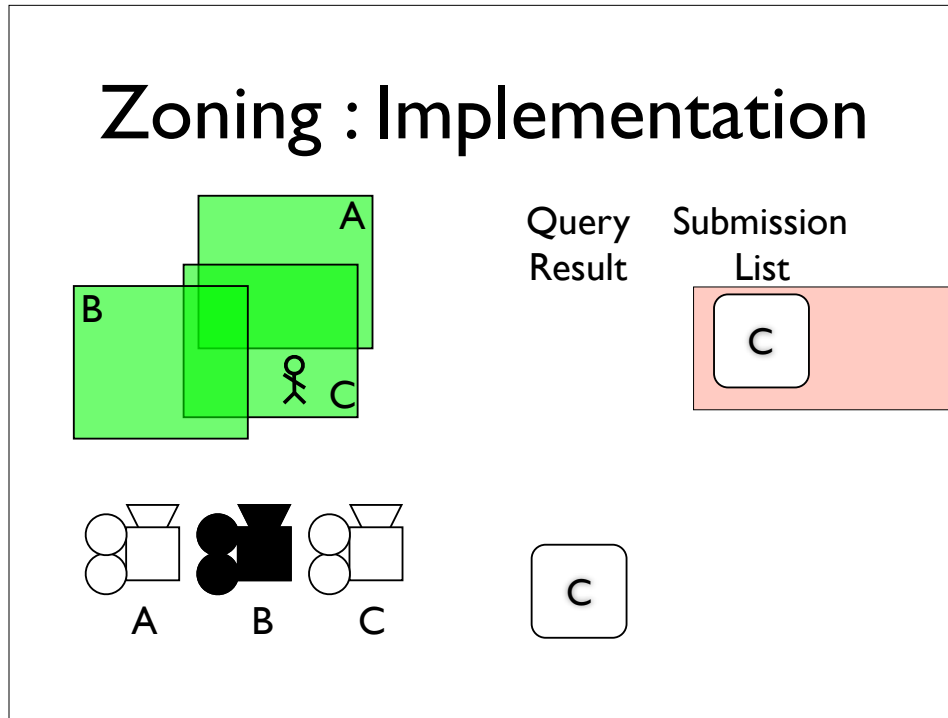
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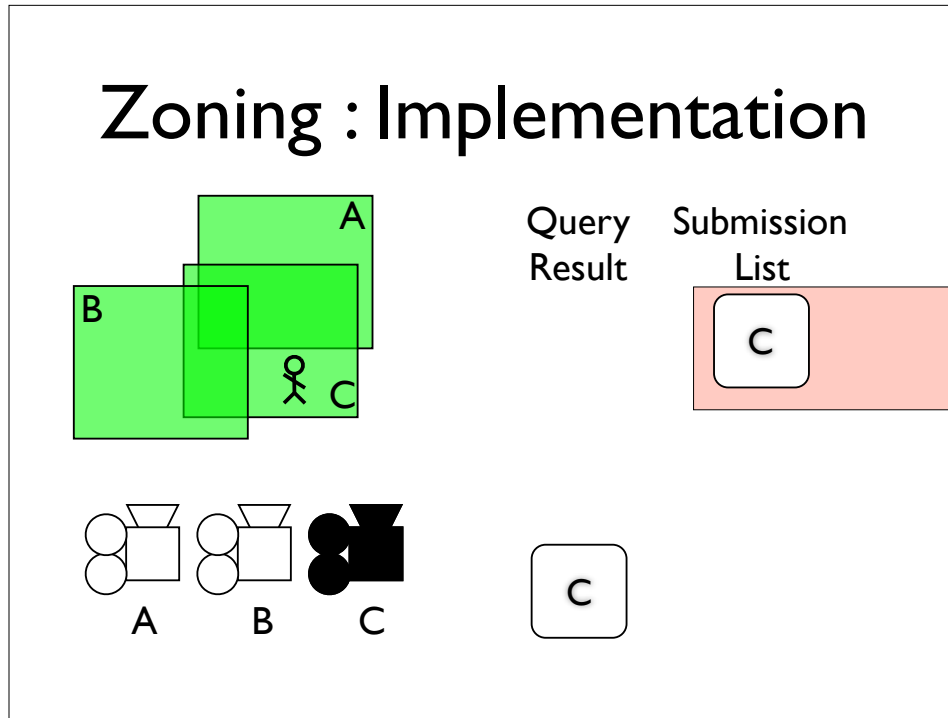
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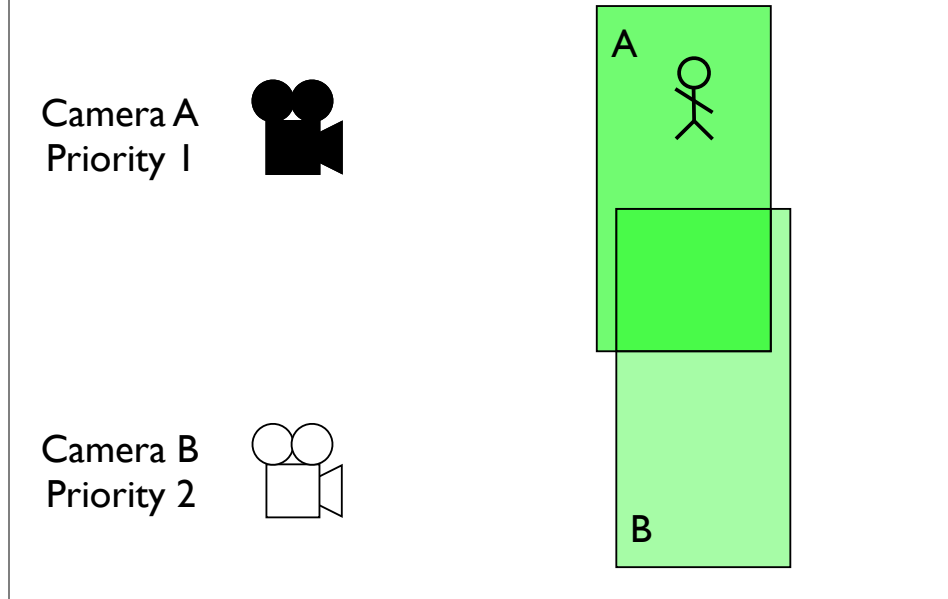
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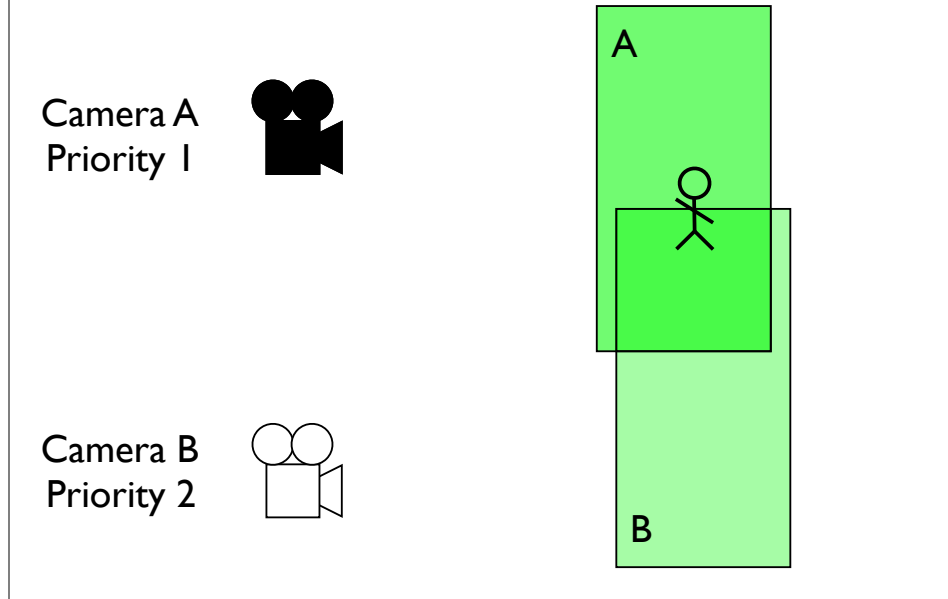


Another wrinkle for finer designer control: Camera priorities (2 is higher)

Higher priorities always override lower ones.

So in this example, we can see that, whenever the player is in zone B, camera B is active, because when we're in the overlap, it has a higher priority.

Zoning : Implementation

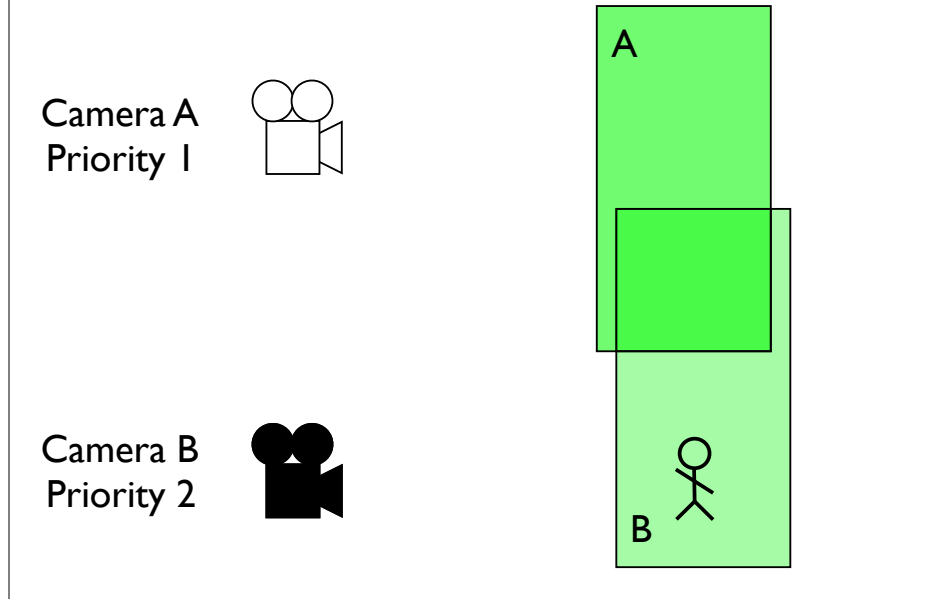


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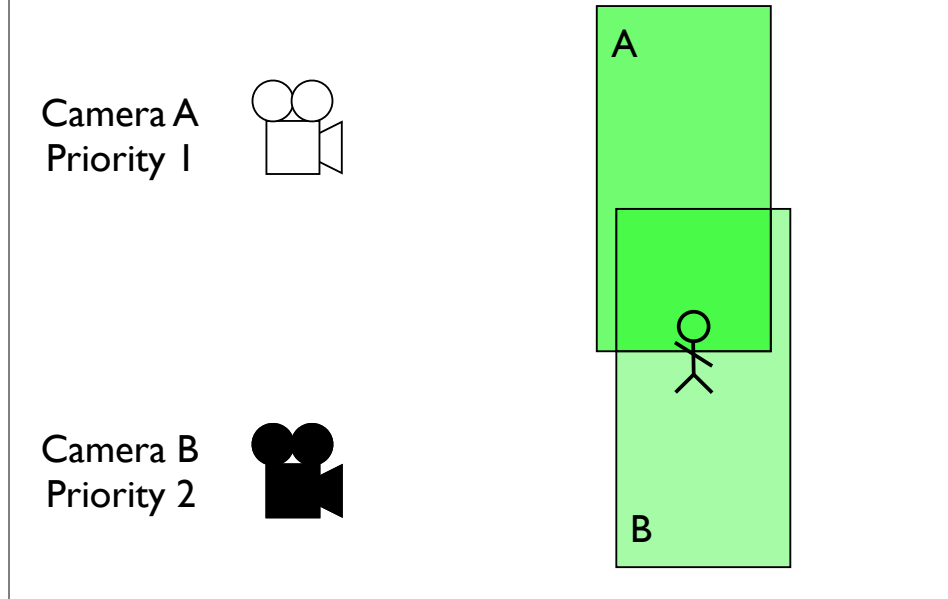


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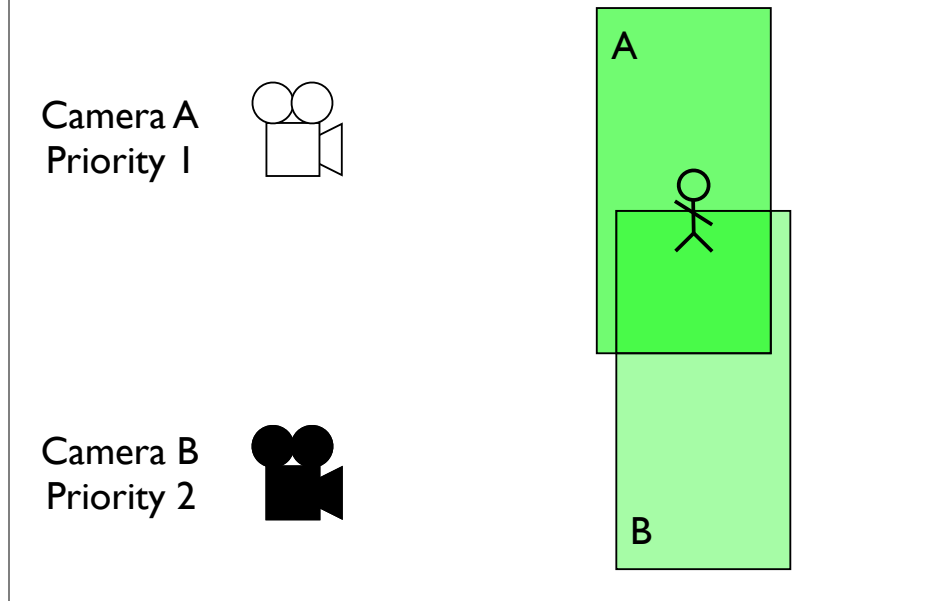


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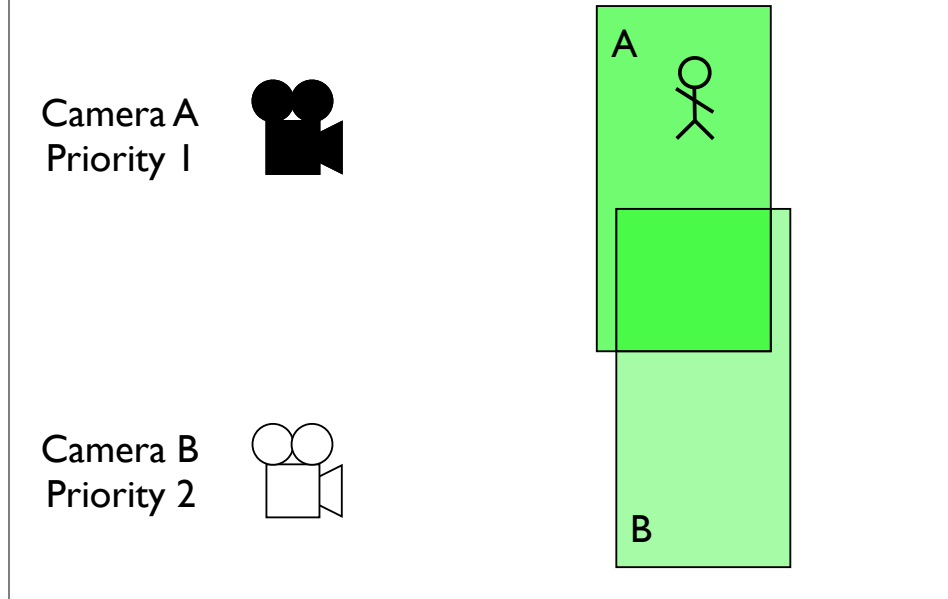


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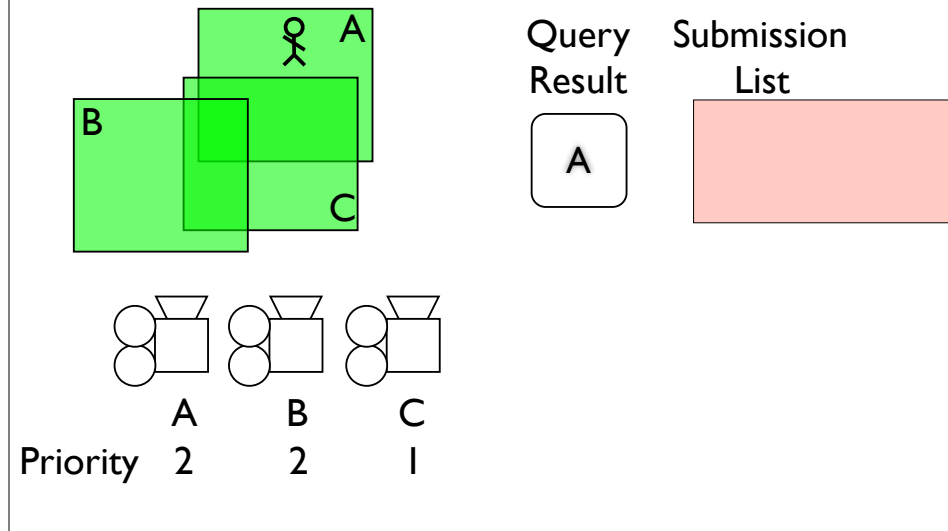


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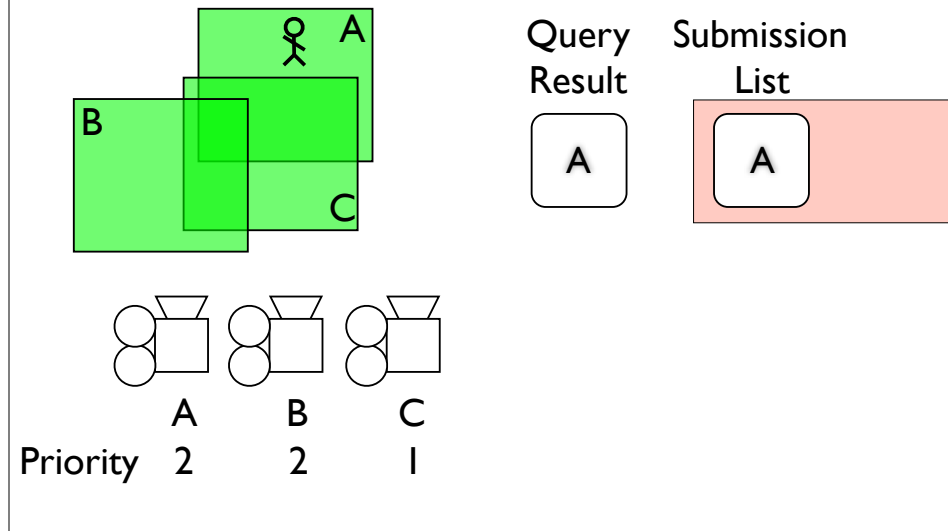
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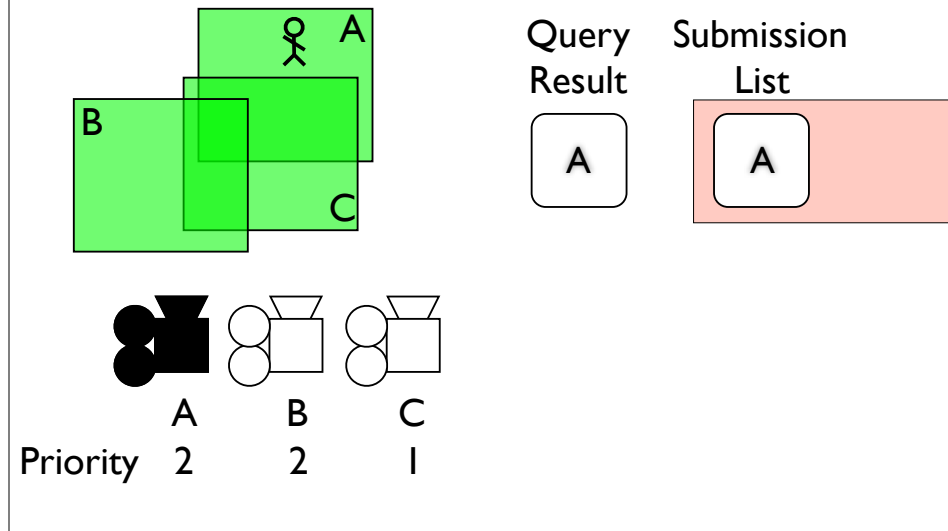
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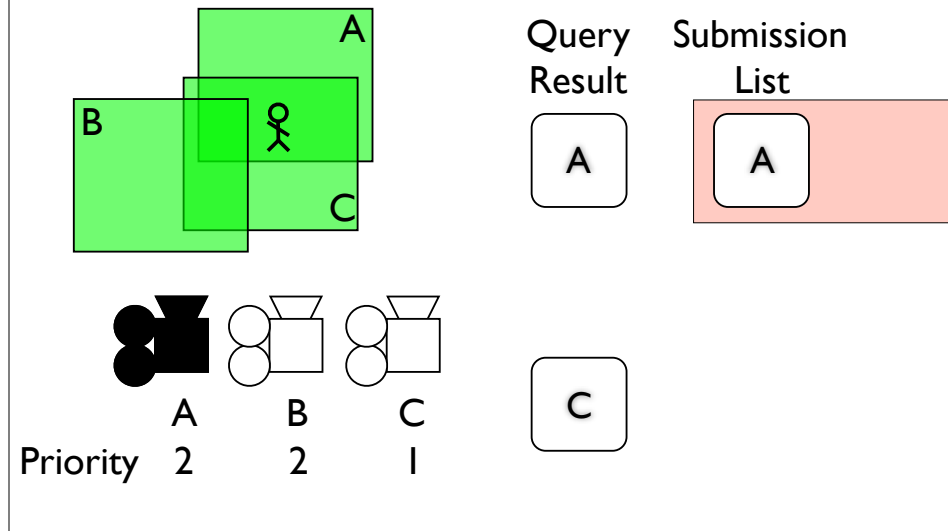
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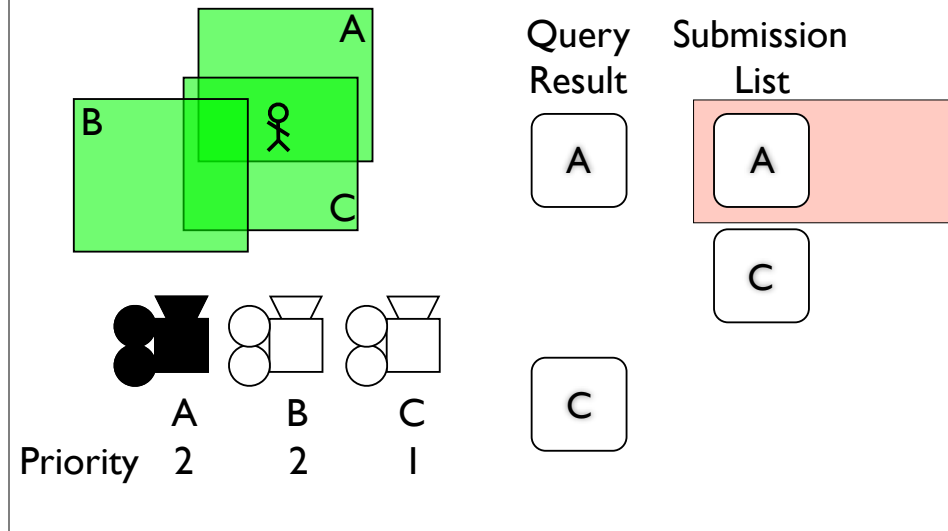
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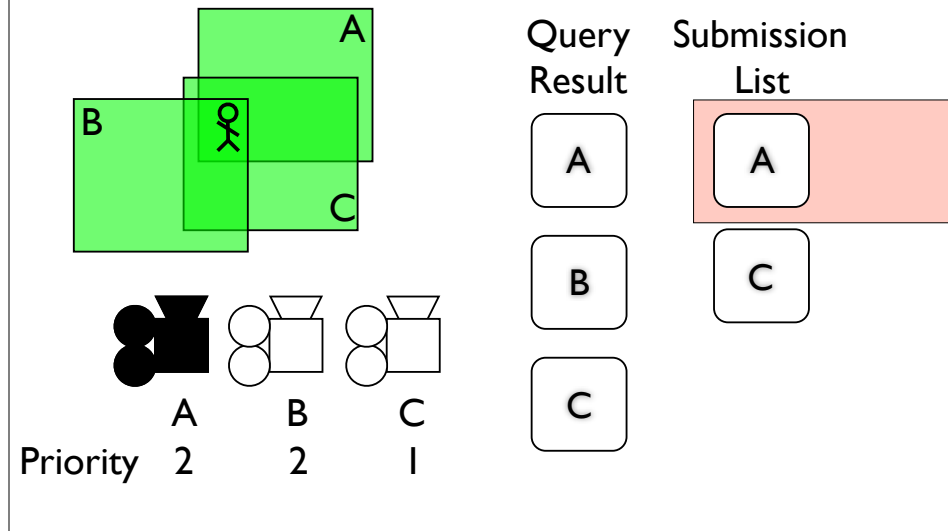
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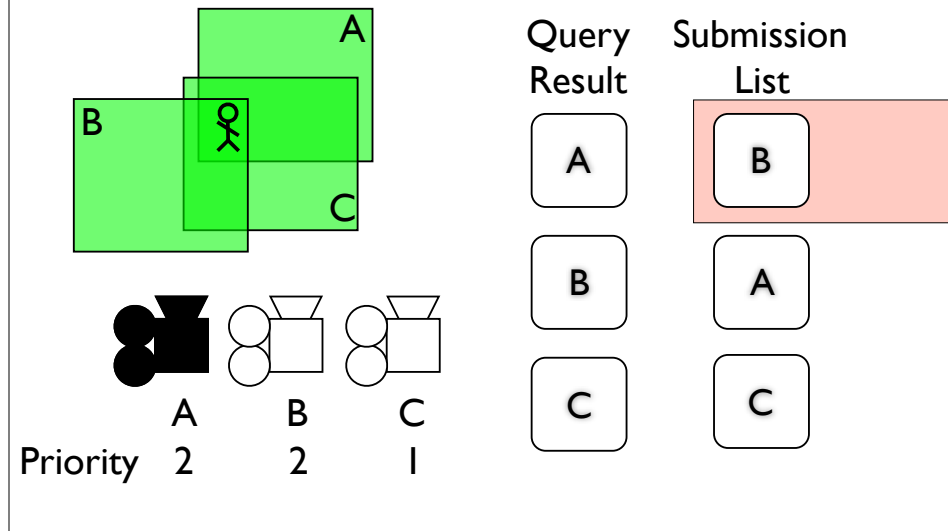
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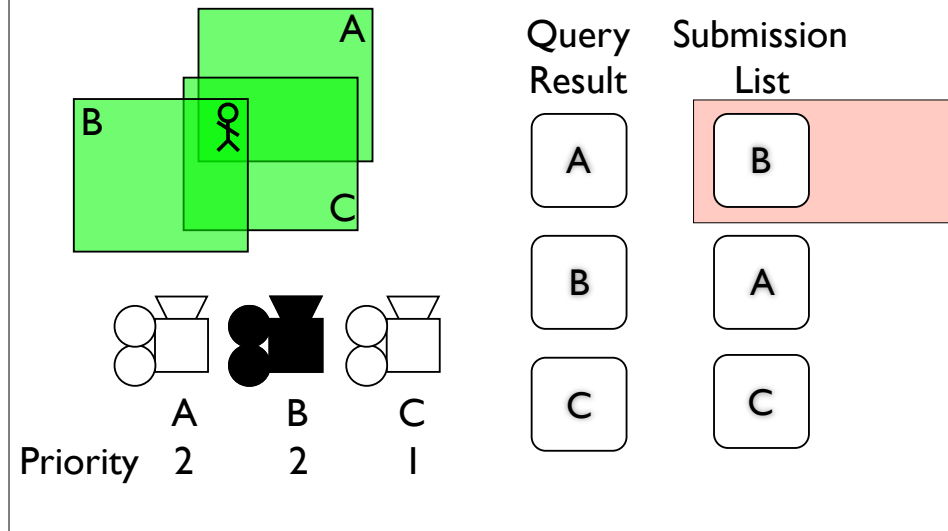
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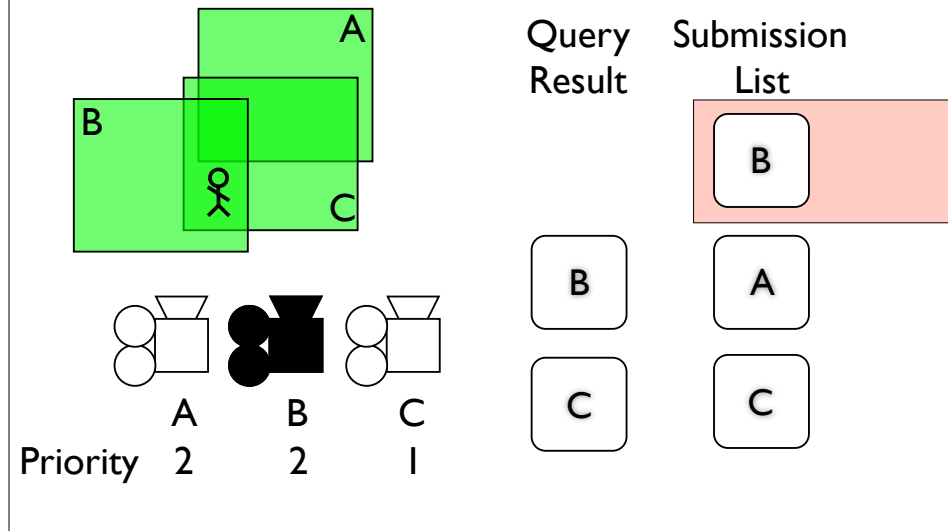
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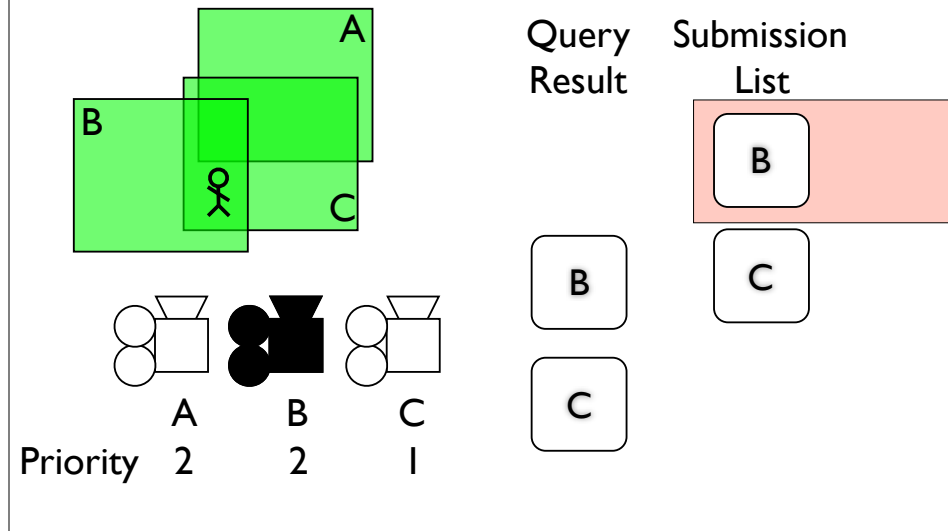
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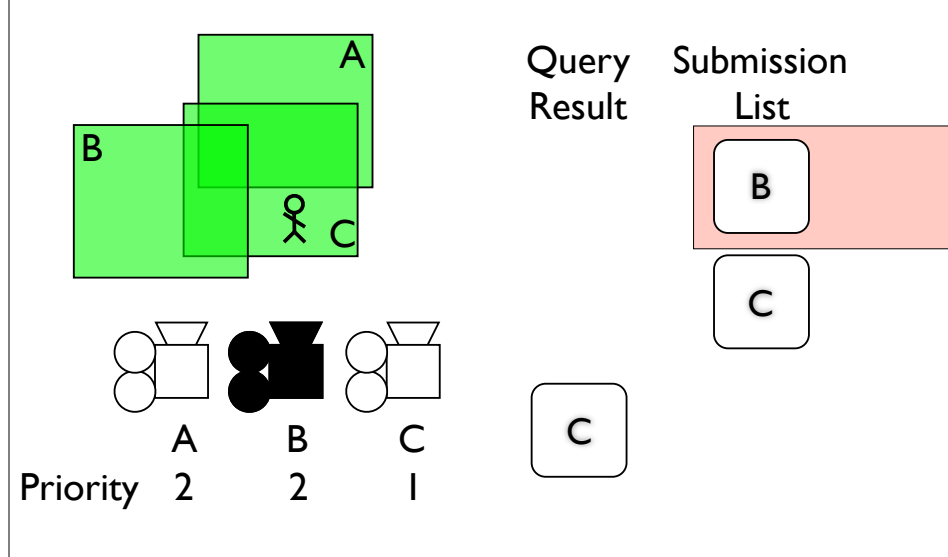
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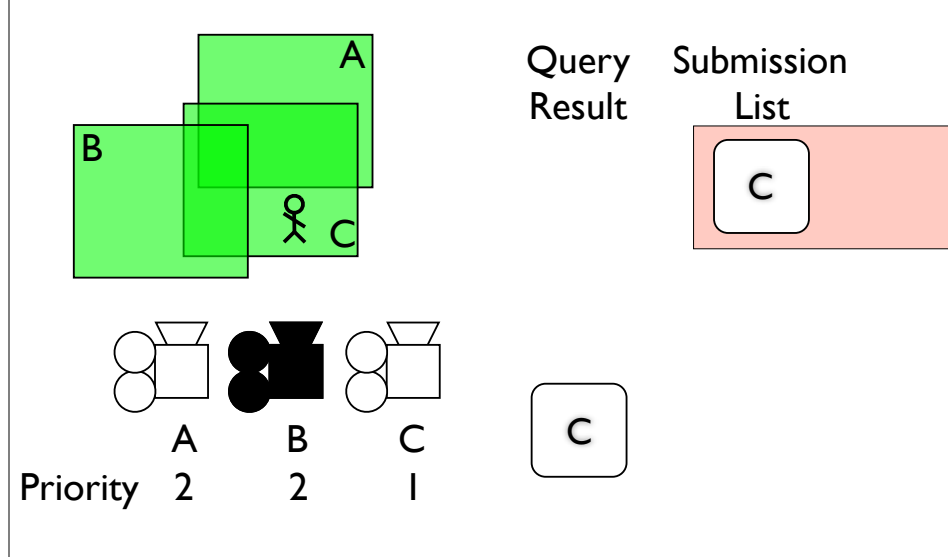
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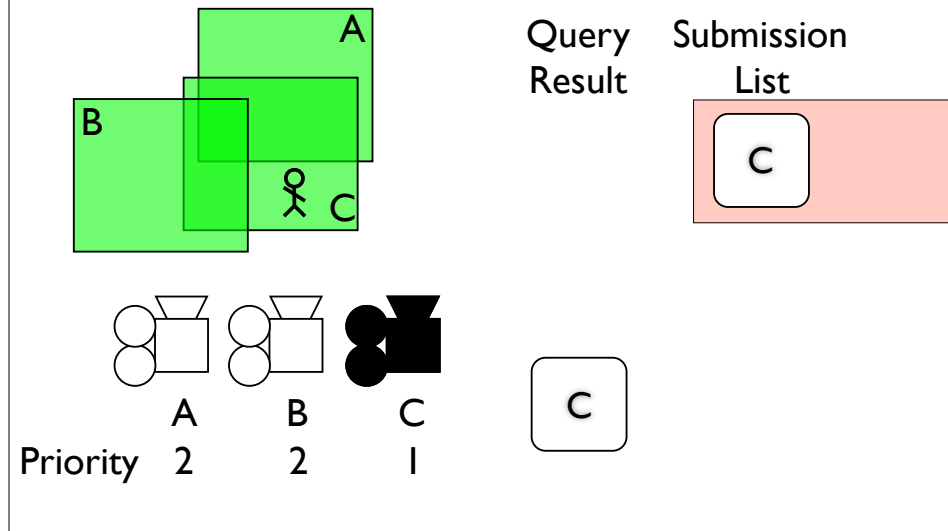
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Zoning Implementation

- Submission List
 - Insert and delete entries to match query results
 - Unless query result was empty
 - Sorted by priority
 - Then by age
 - Top entry is active camera

SUMMARY:

the submission list contains the current set of cameras up for consideration

insert and delete entries to match the current query results, assuming we got any

If the query was empty, then we hold the previous frames submissions (never want NO camera!)

Sorted by priority, then age, or rather, by how recently the camera was submitted

Which results in the newest, highest priority, camera sitting at the top of the list.

Overview

- Zoning
- Dynamics
- Blending
- Rails

Overview

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So zoning is about choosing a camera. But once you have chosen a camera, there are still a number of issues to resolve about how you **use** the camera, such as how far away it is from the player, what angle it is looking at the player from, etc. This is what dynamics is about.

Dynamics : Objectives

- Control the display of the Player
on the screen:
 - Position
 - Angle
 - Size

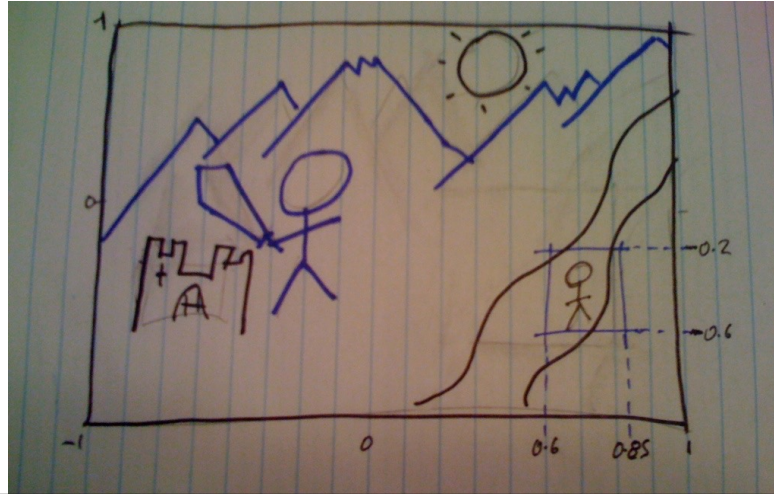
So when we talk about dynamics, we're really talking about moving and orienting the camera to control certain display characteristics of the player.

The players position on the **screen**

The angle that we are looking at them from.

and their size, which is a function of their distance from the camera, and the Field of View

Dynamics : Design



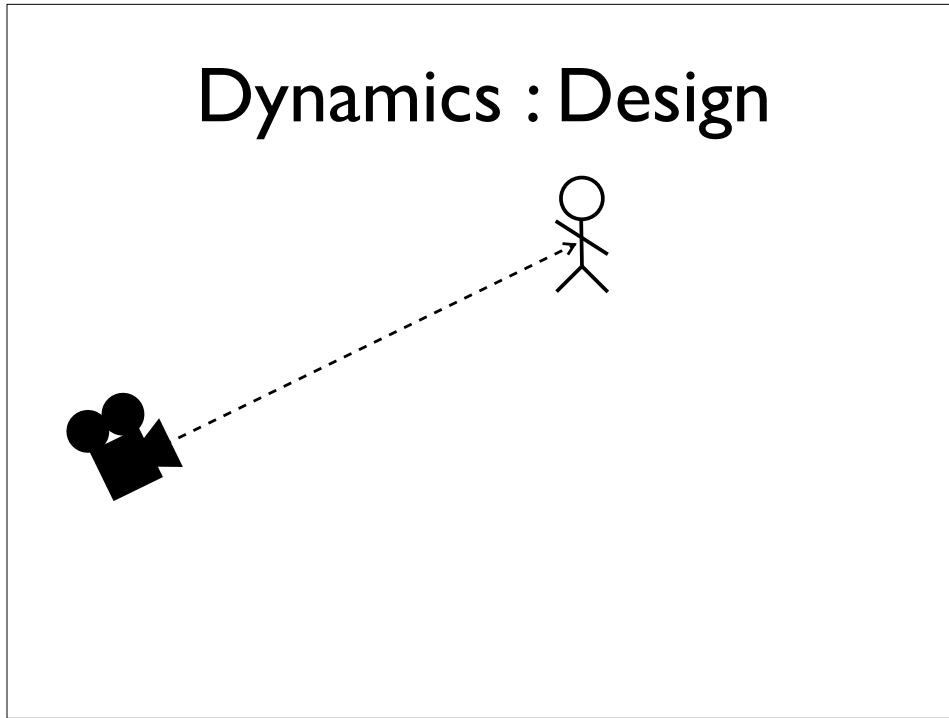
In order to control the players position **on the screen**, we define an area of the screen within which it is “safe” for him to move. Safe to move without having to move the camera to keep him in that zone.

We define a rectangular space on the screen, known as the Safe Zone. (If we want the player to always be at a particular position, we can shrink the boundaries down to that point.)

This is represented to the designer as a pair of **resolution independent** co-ordinates

...and at runtime we can overlay the safe zone on the real time display

Dynamics : Design

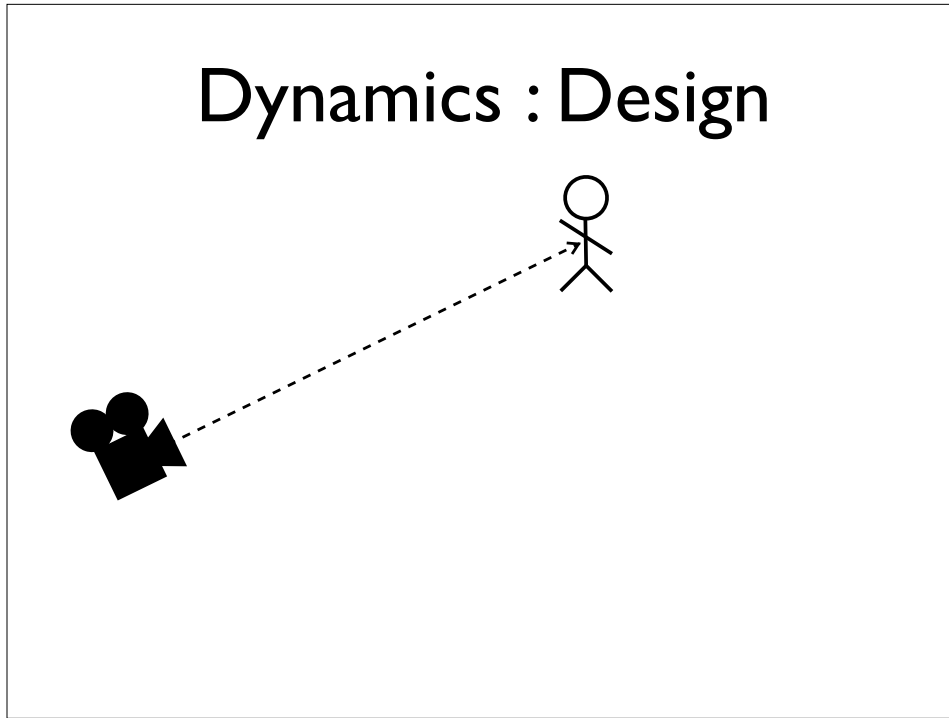


Both the position of the player on the screen and the angle at which we view him depend on the **angle** between the camera and the player.

We can specify the angle that we're viewing the player from as a fixed value. (Animate)

[In which case we use the orientation of the camera (e.g., in Maya) to define that value.]

Dynamics : Design



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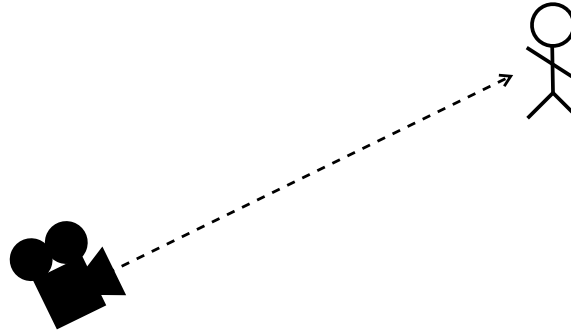
Dynamics : Design



Slightly more flexibly (camera doesn't move so much, which can be disconcerting), is to calculate it relative to a fixed position in space. (Animate 3 clicks)

[Now because each dynamic camera is still defined by a camera in Maya, we already have a convenient fixed position. That of the camera node in Maya.]

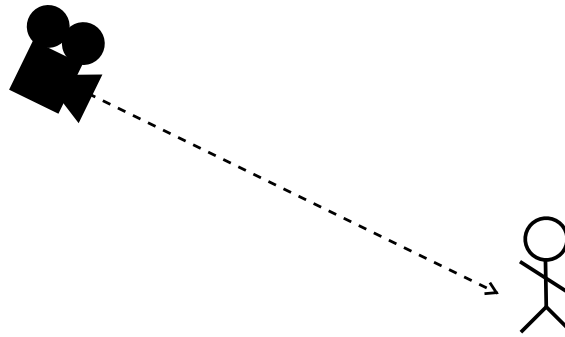
Dynamics : Design



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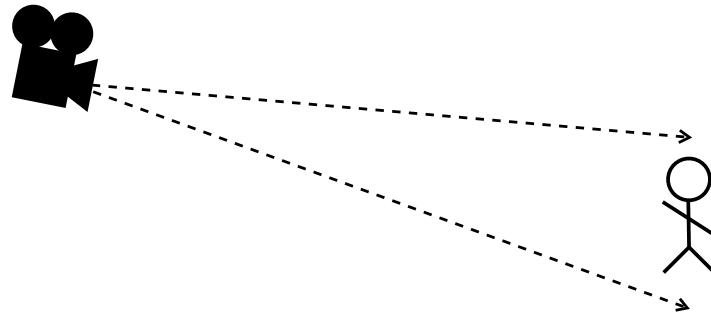
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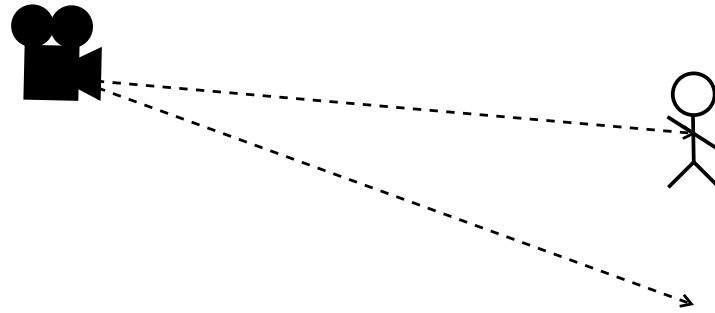


Now combining previous two ideas, we can *constrain camera within a fixed range*, and then move it when needed. (Animate 4 clicks)

[Now to specify that range, we again, use the orientation of the camera node in Maya,]

plus or minus a fixed amount defined in the cameras attributes.

Dynamics : Design

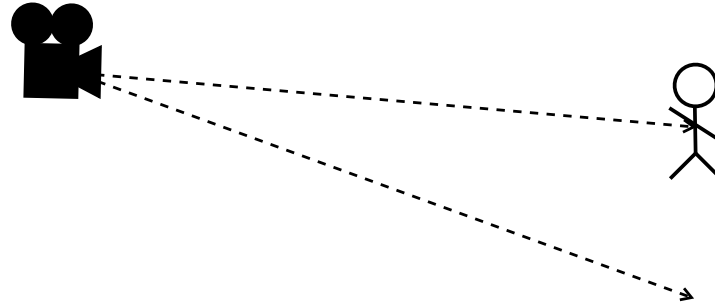


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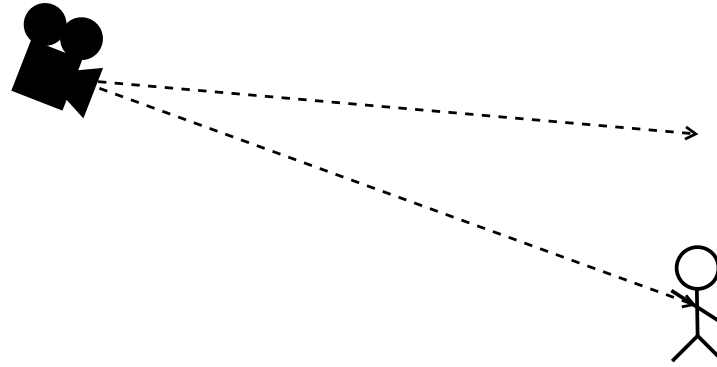


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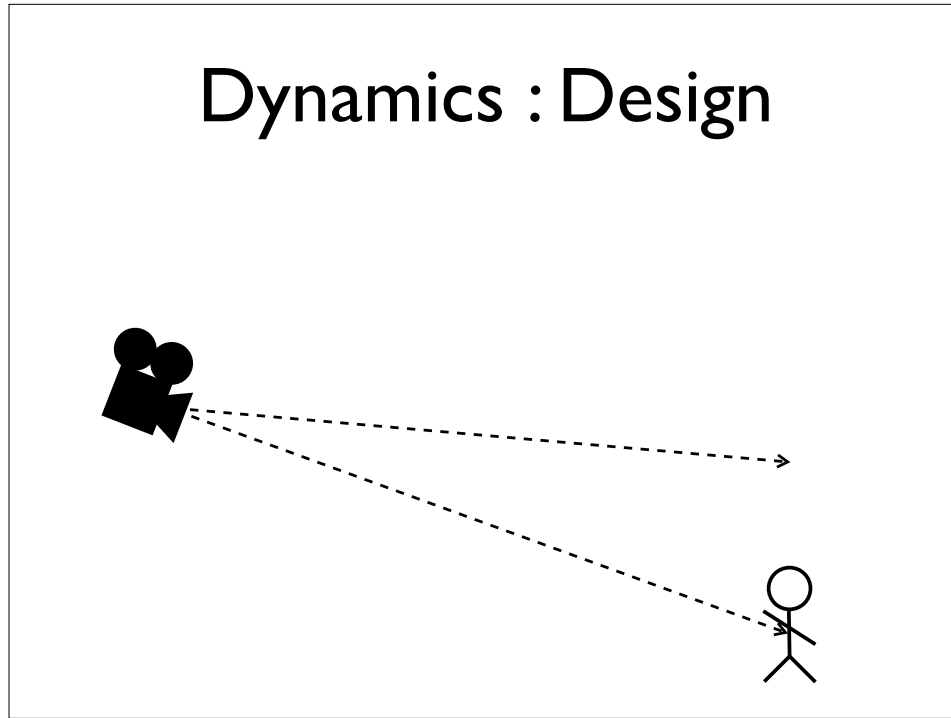


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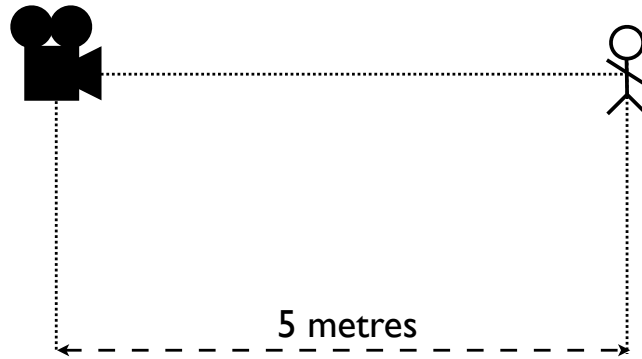


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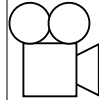
Dynamics : Design



Finally we control the **size** of the player on screen, by controlling his distance from camera.

Again, the simplest way of specifying this, is to *fix* it to a set value. (No animation)

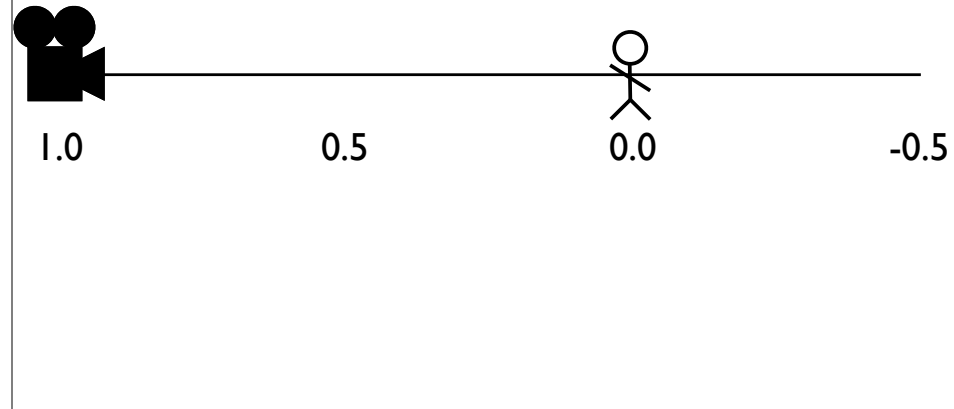
Dynamics : Design



Or, more flexibly, we can specify it as a *proportion* of the distance from the camera node to the player

With negative values being behind the player, and in those cases, we automatically turn the camera around, to look back at the player

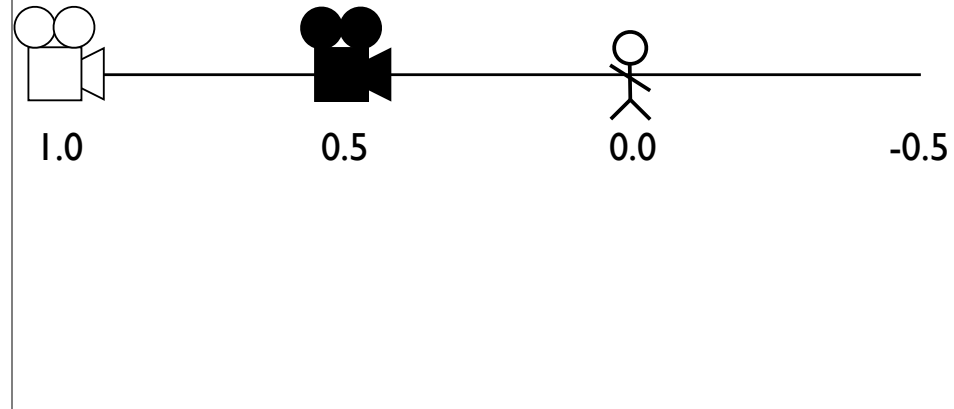
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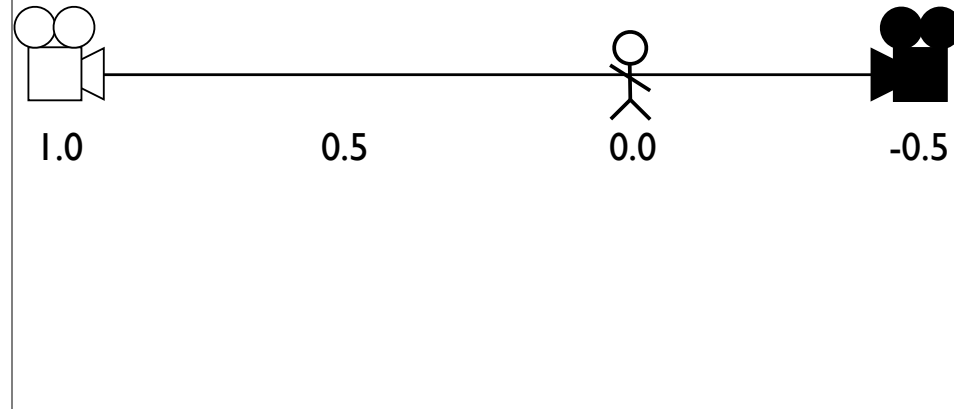
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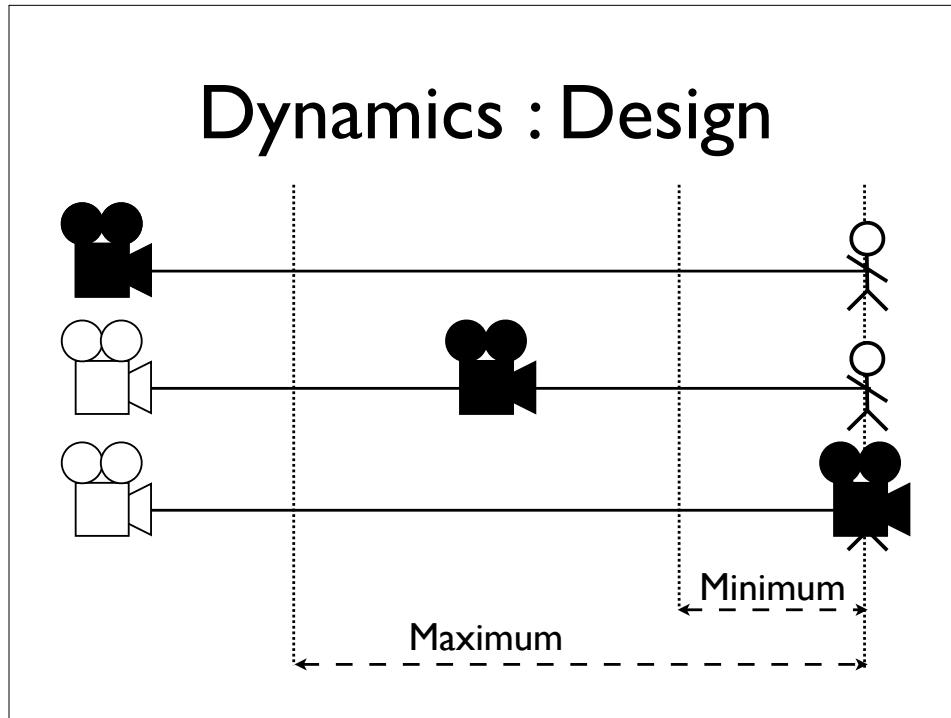
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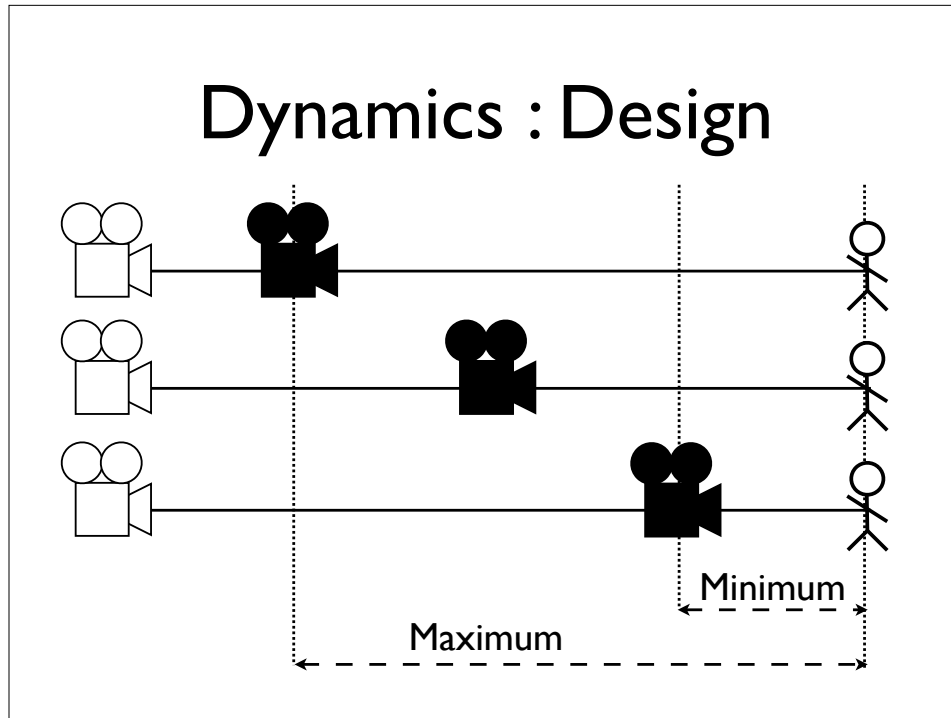
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Then we allow the designer to set a range of valid distances for the camera.

Move the camera to ensure that it **never gets too far from, or too close** to, the player.
(Animate 1 click)

(Similarly to the safe zone, we can collapse these min/max constraints to represent a fixed distance.)



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Dynamics : Implementation



SUMMARY: So that's how we let the **designer** control the three defining properties of the camera

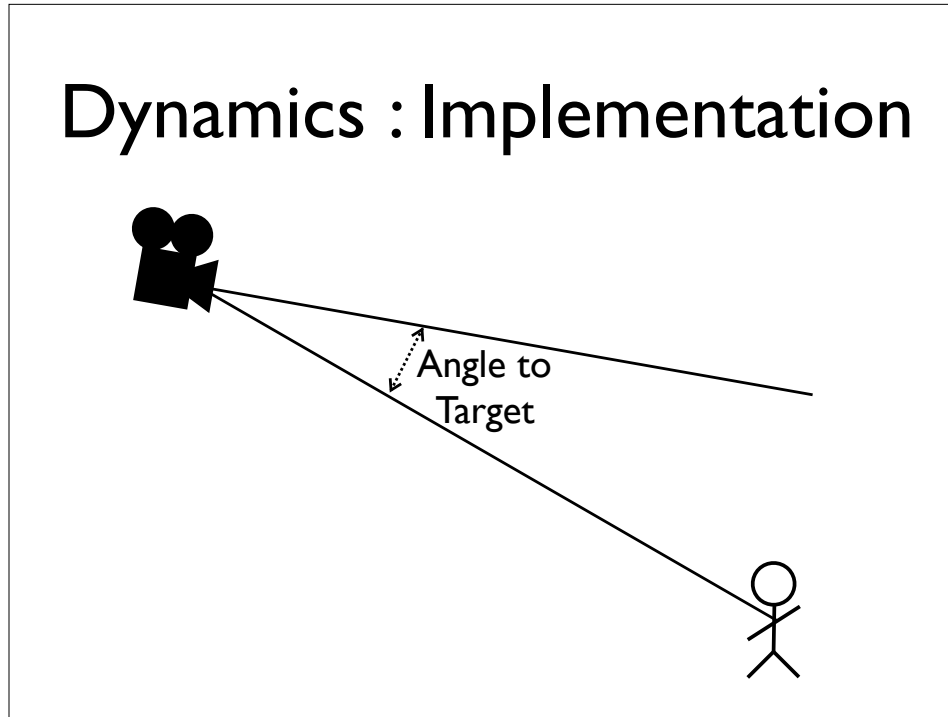
- * the position of the player on screen
- * the angle we're looking at him from, or rather, the orientation of the camera
- * and his size, or rather, the distance from the camera to the plane of the target, perpendicular to the look vector

internally we calculate, constrain, and store these as

- * the angle from the look vector of the camera, to the target. This is a 2d diagram, but in 3d this is a pair of angles, from the horizontal, and the vertical, in camera space. We use the angles, so that we can easily represent the cases where the target is behind the camera. It also makes it easier to apply the safe zone constraints, as these are internally represented as a pair of angular ranges in the same space.
- * the angle of the camera to the world, again, 2d diagram, consider that dotted line to be zero degrees. In 3d we use an euler, because they're easy to manipulate and visualise.
- * and the distance to the target plane

* we package these up with the position of the target, and we have enough information to calculate the actual position and orientation of the camera in the world

Dynamics : Implementation



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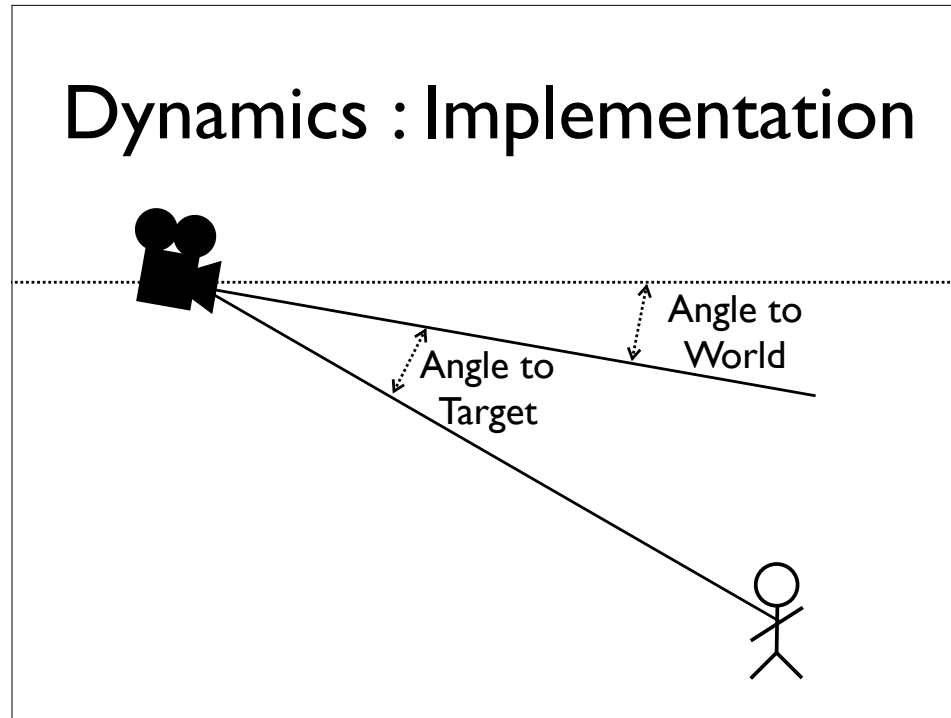
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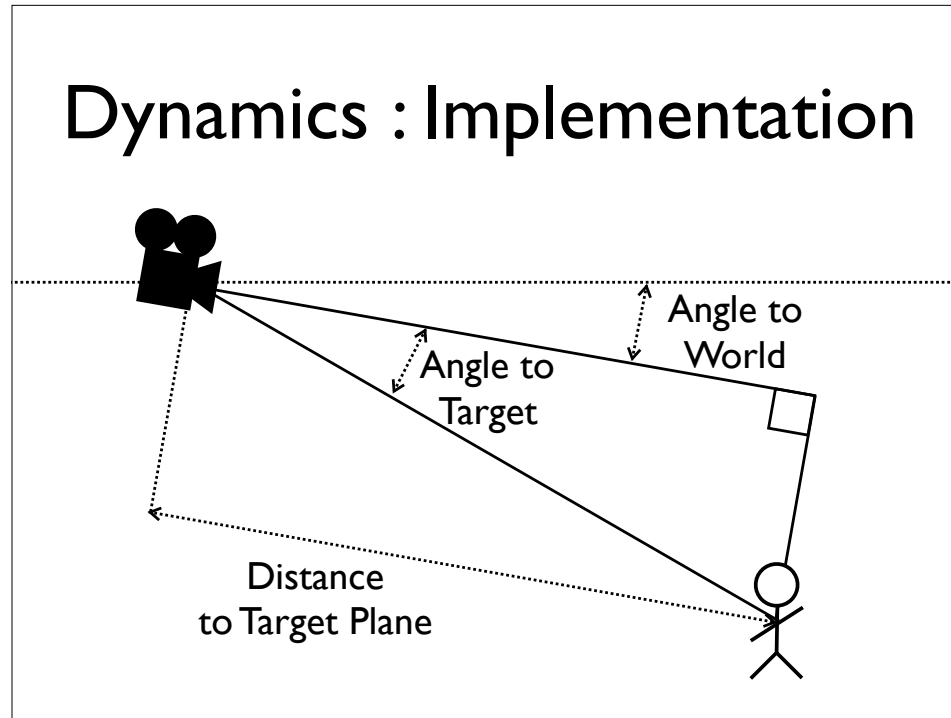
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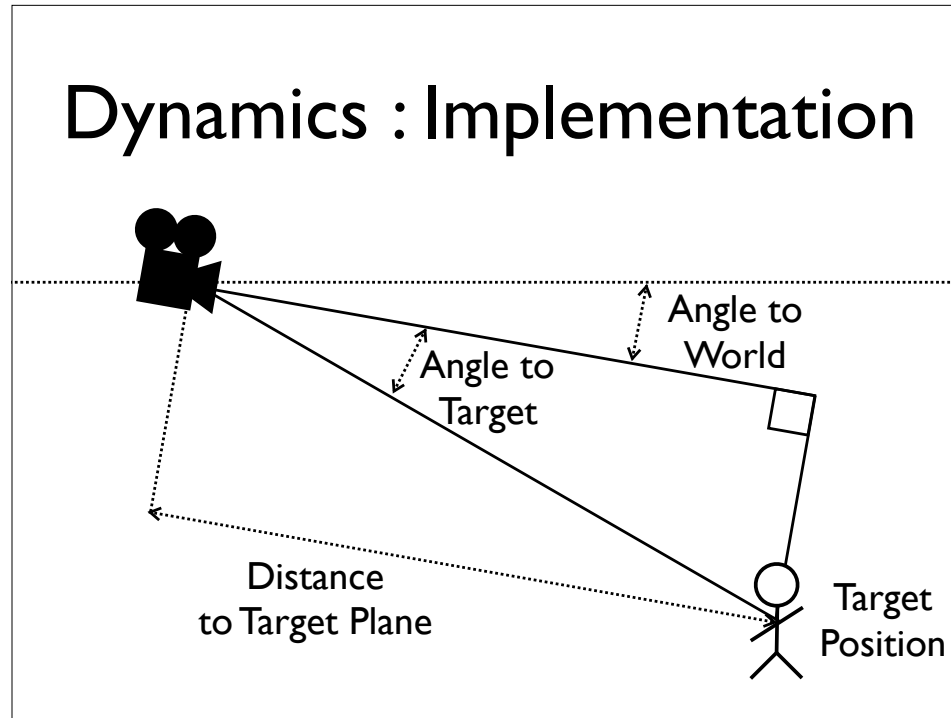
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Dynamics : Implementation

- *Calculate* Angle from Camera to Target
- *Constrain* Angle from Camera to Target
- *Calculate* Angle from Camera to World
- *Calculate* Distance from Camera to Target Plane
- *Constrain* Distance from Camera to Target Plane

Overview

- Zoning
- **Dynamics**
- Blending
- Rails

Overview

- Zoning
- Dynamics
- **Blending**
- Rails

Smoothing transitions between cameras (i.e., not jump cuts).

Blending : Overview

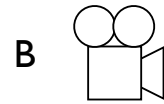
- Timers
- Ease
- Blend Space

Timers, which track and update each blend

Ease, which controls the smoothness of a blend

and Blend Space, where I'll define what a blend between two cameras actually does.

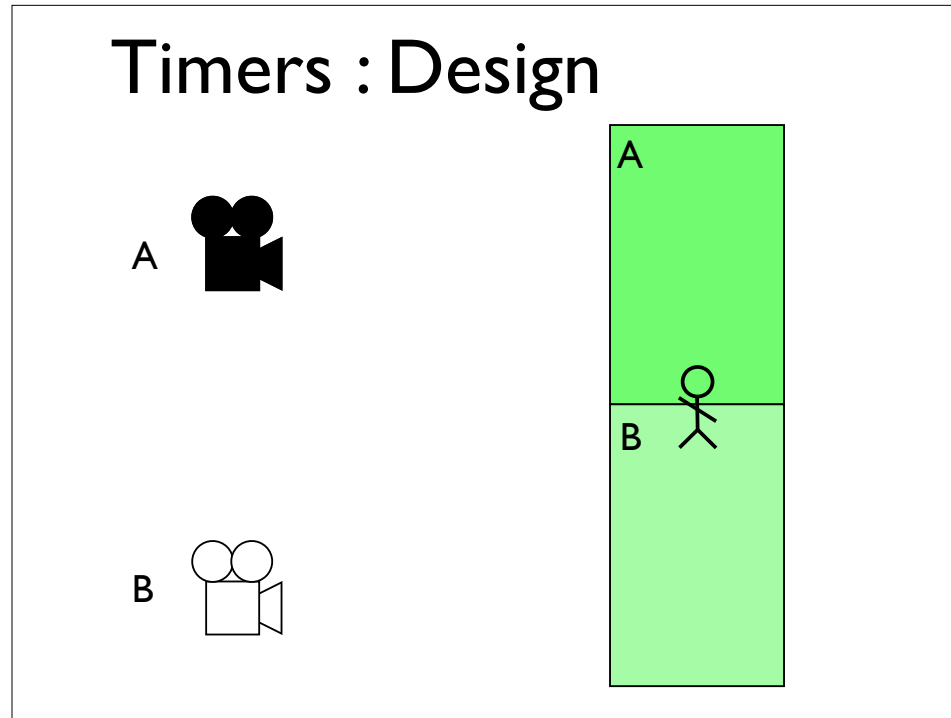
Timers : Design



when we start a new camera, we don't cut to it, but blend into it over a fixed period of time.

(Animate cut 2 clicks)

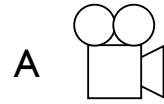
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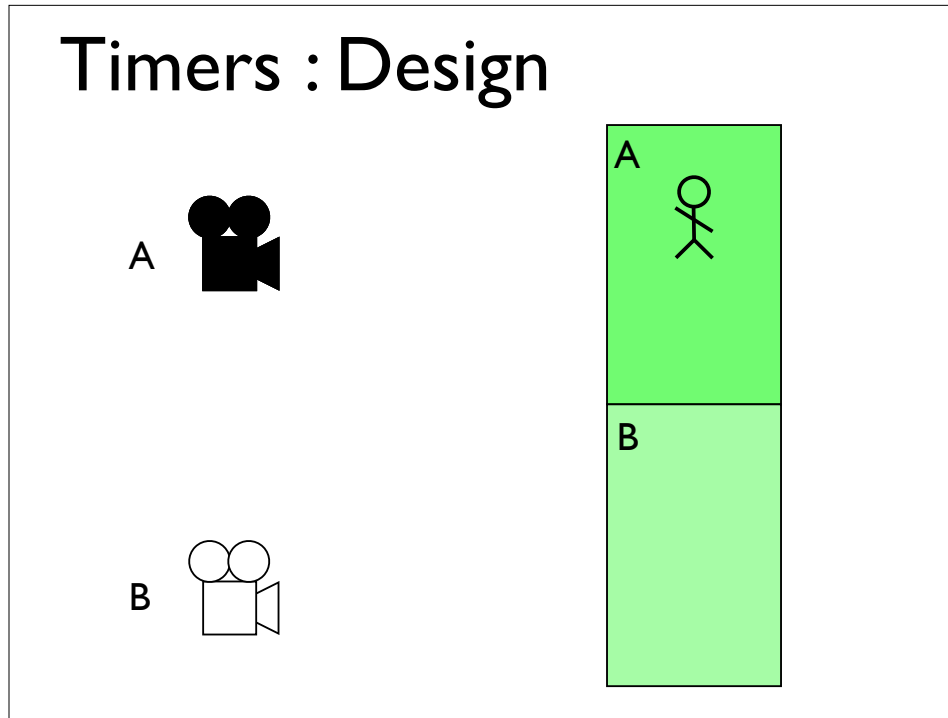
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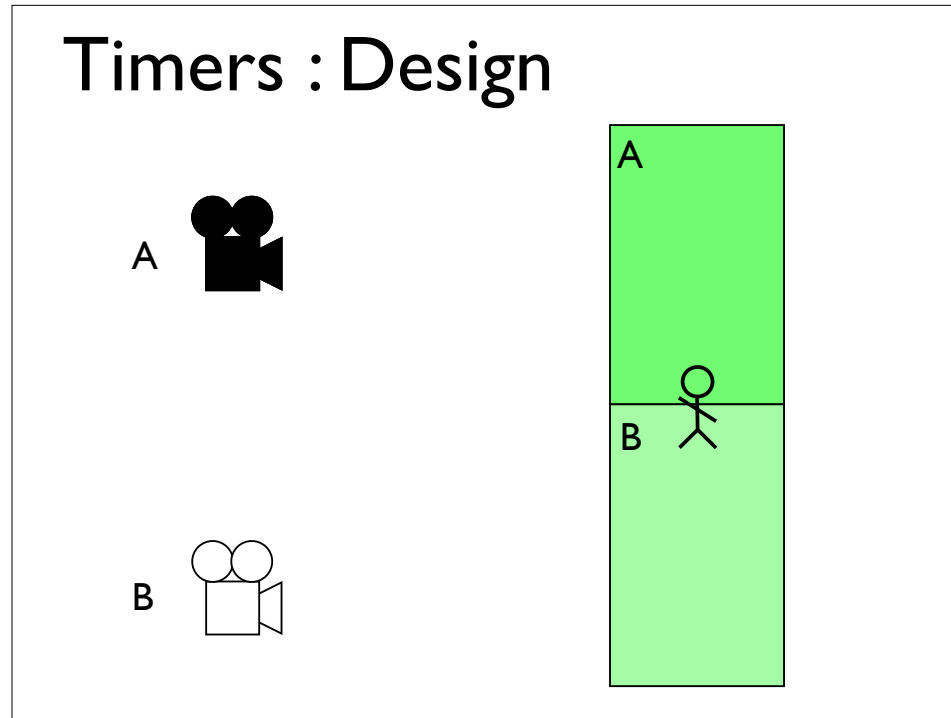


And when I say blend, I mean **creating a third camera from varying proportions** of two other cameras.

So when we start the second camera, what actually happens is that a phantom third camera moves from the first camera to the second. It's position and orientation determined by a blend of the two cameras, driven by a timer. (Animate timer blend 2 clicks)

When we move into a zone that references a new camera, as well as starting that new camera, we also start a timer for it.

Timers : Design

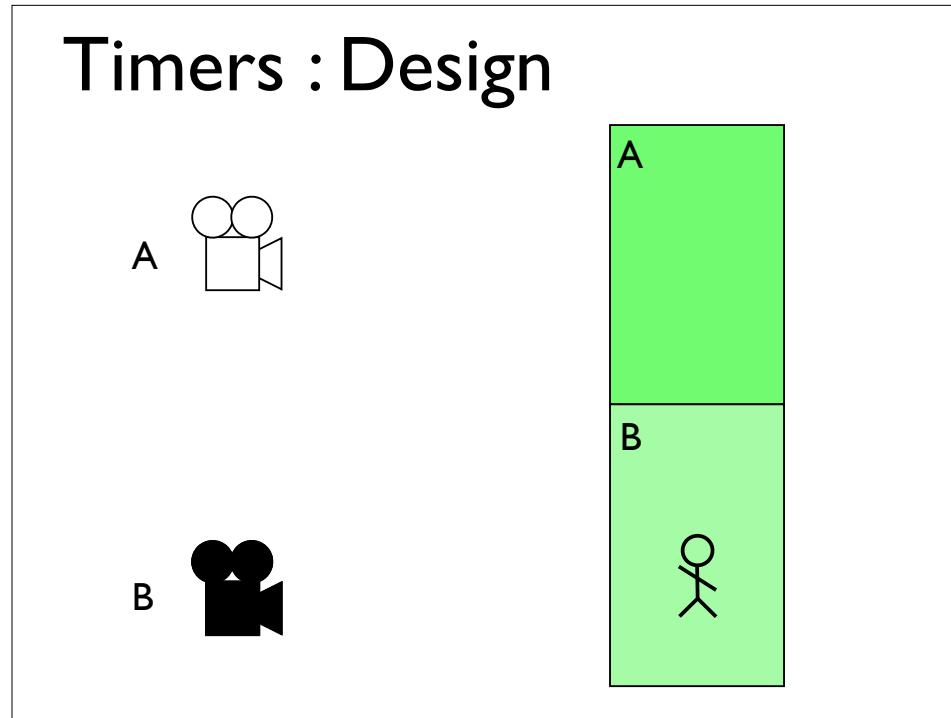


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Timers : Implementation

- Timer List
 - Entry is a camera fading in
 - Camera can have multiple timers in list
 - FIFO
 - New timers inserted at the top
 - When a timer completes, all timers below it are removed

Now if the player is moving between zones, faster than their cameras fade in, then it's entirely possible that we'll be running multiple timers, simultaneously, so we need to store these timers in a list.

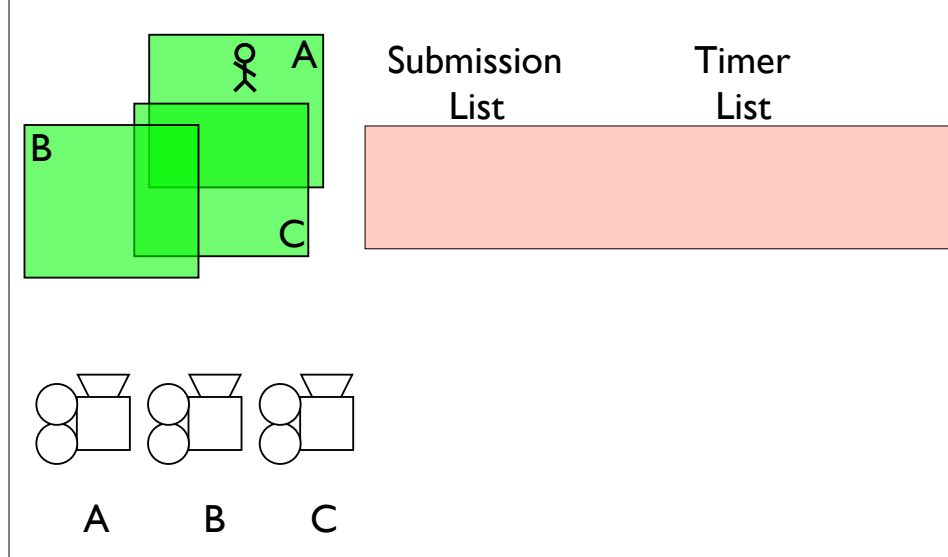
In fact, you may be fading back into a camera you're already fading out of. In these cases you may be tempted to try and reverse a running timer. I initially tried this, but couldn't get it to work smoothly, as you need to correct all the timers between the two instances.

Instead I decided to let each timer play out, and to track new timers separately. New cameras fade in, and by fading in, reduce the contribution of the cameras below them in the list.

So cameras don't fade out by themselves, they fade out as a result of a new camera fading in,

The timer list is a FIFO. New timers get inserted at the top, and timers below completed timers fall out of the bottom.

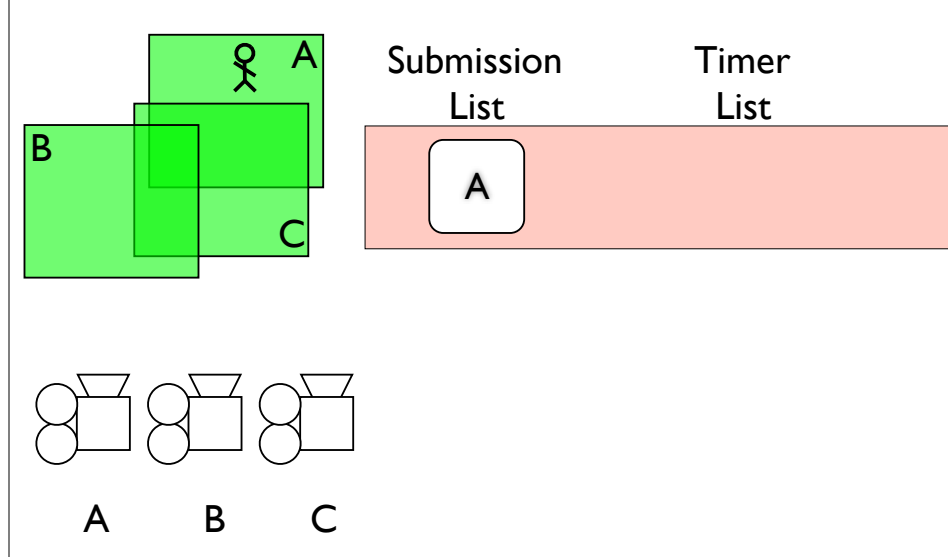
Timers : Implementation



Note the red bar at the top of the lists, this is because the top of the submission list, and the top of the timer list should be the same camera. This is the active camera. The camera that we would cut to if we weren't fading it in.

zone a -> top of submission list -> starts new timer, timer list is empty, so it starts immediately
zone c -> top of submission list -> starts new timer, camera is now a blend of a and c, hence grey
zone b -> increment old timers, start new timer, camera is now a blend of a,b and c
out of zone a -> camera c's timer has completed, drop camera a
out of zone b -> c at top of submission list again -> start new timer, note that c is in the timer list twice
wait a second -> b's timer completes, drop the entries below it
wait another second -> c's timer completes, drop the entries below it, and we're back with c at 100%

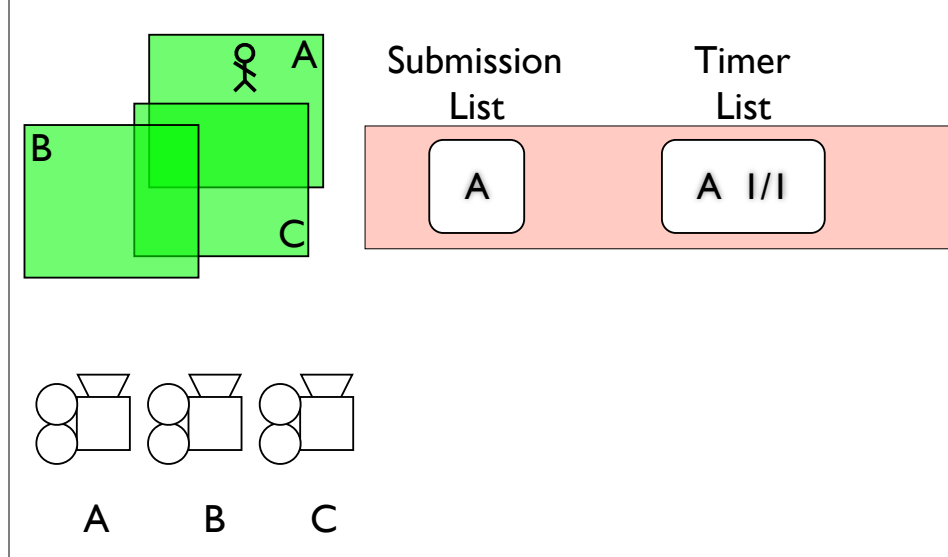
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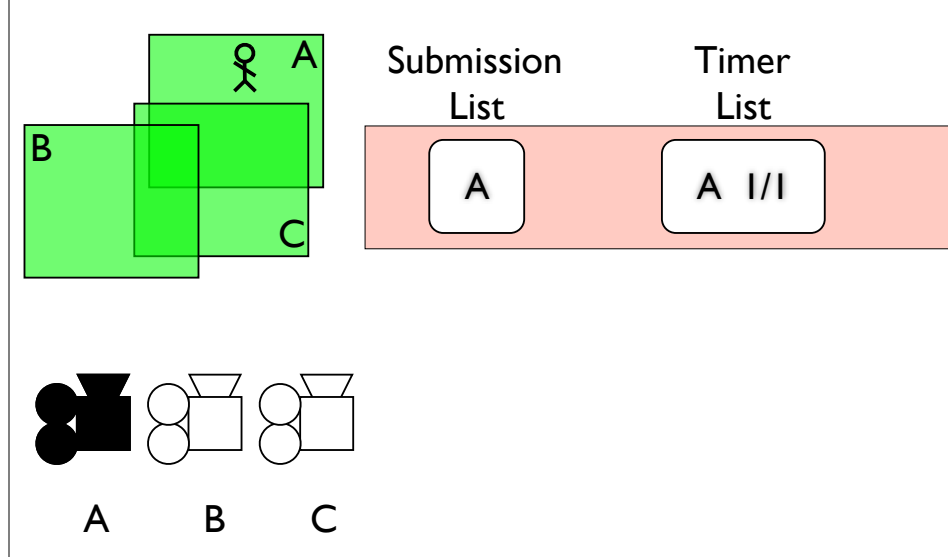
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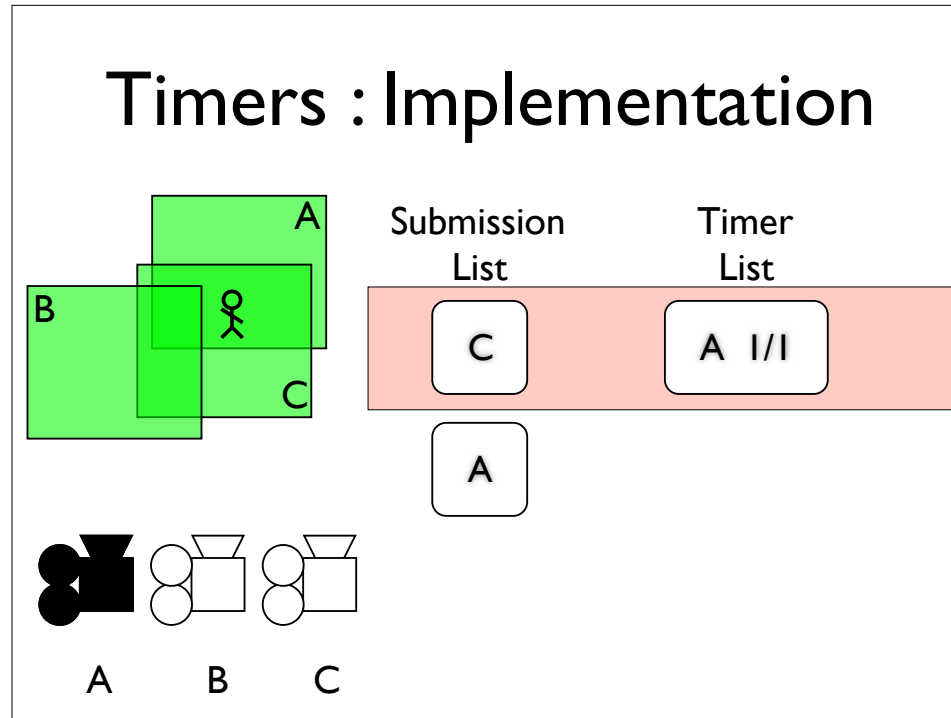
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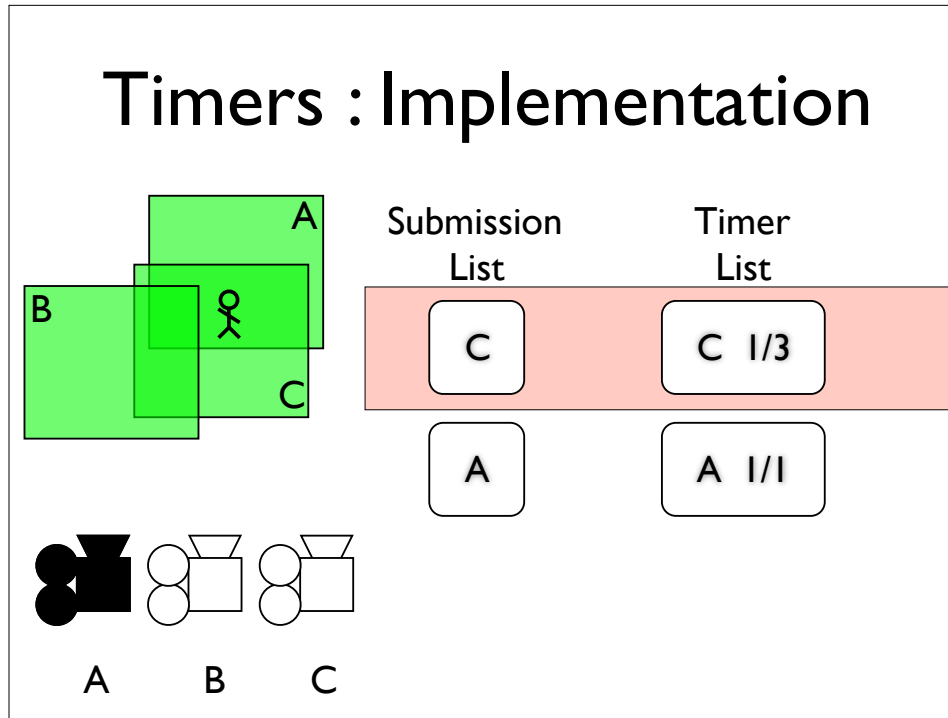
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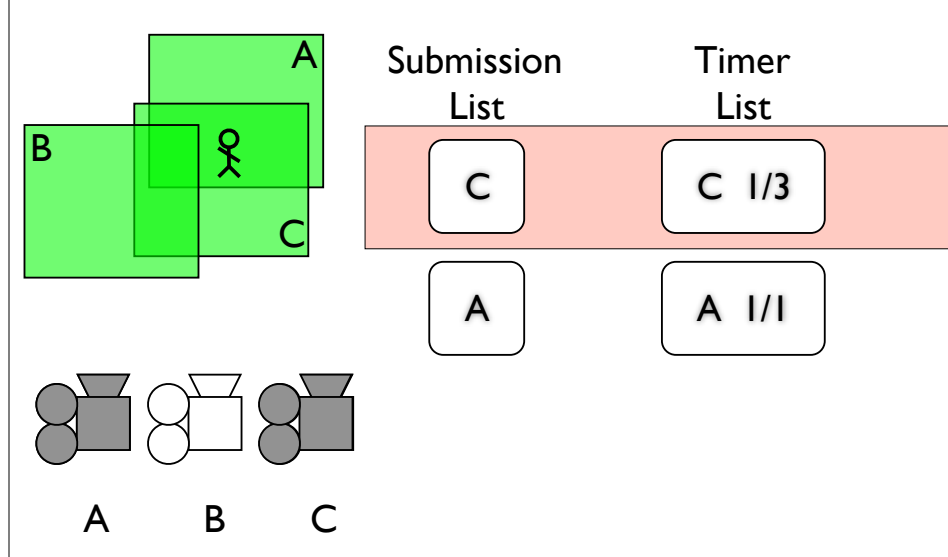
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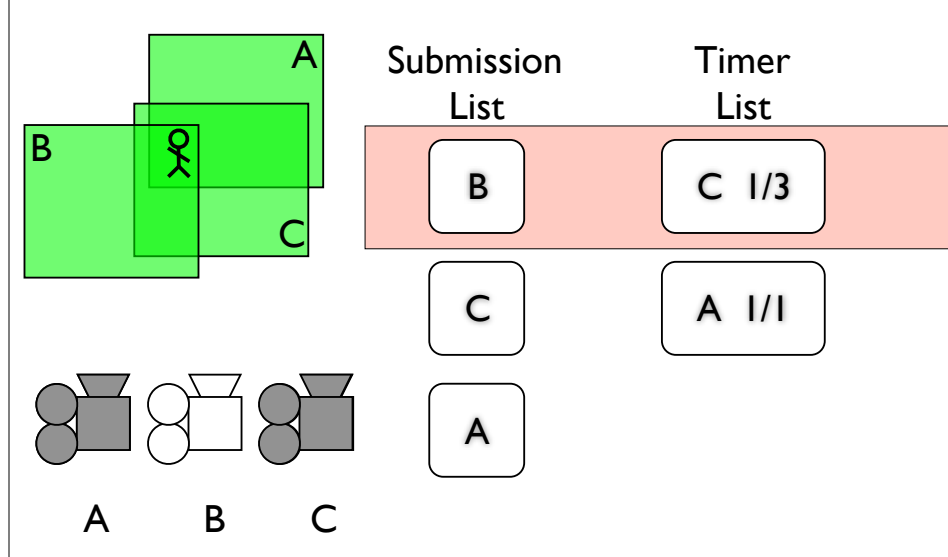
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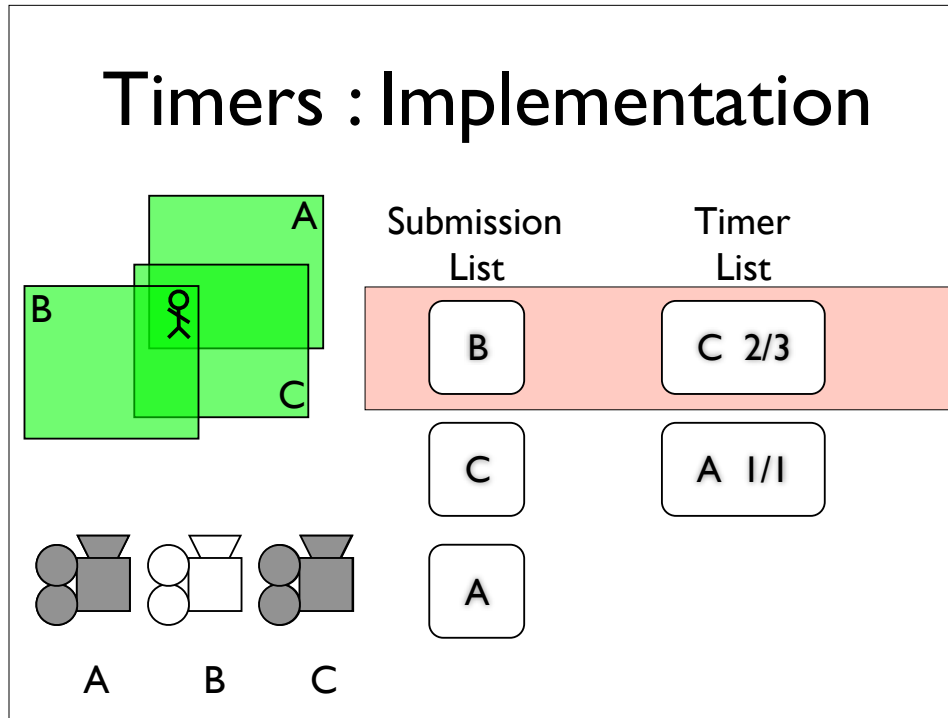
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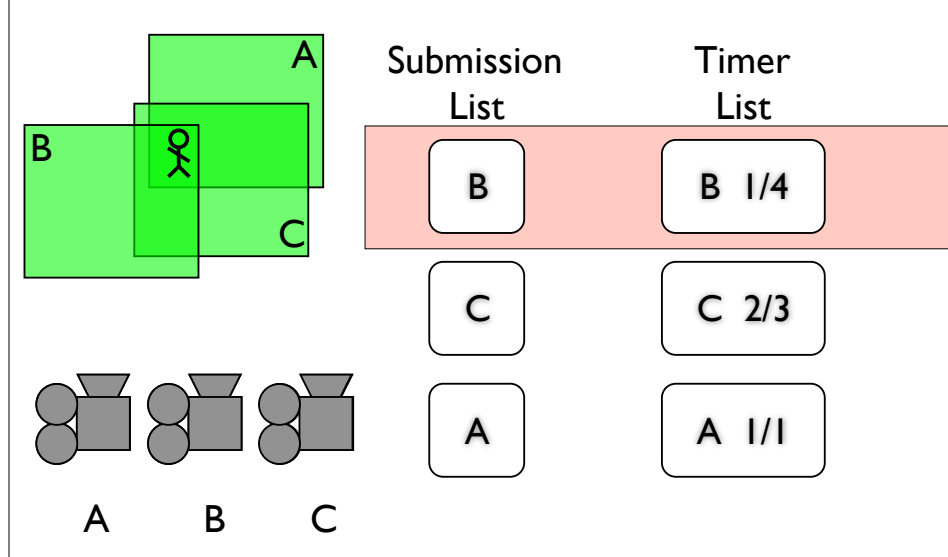
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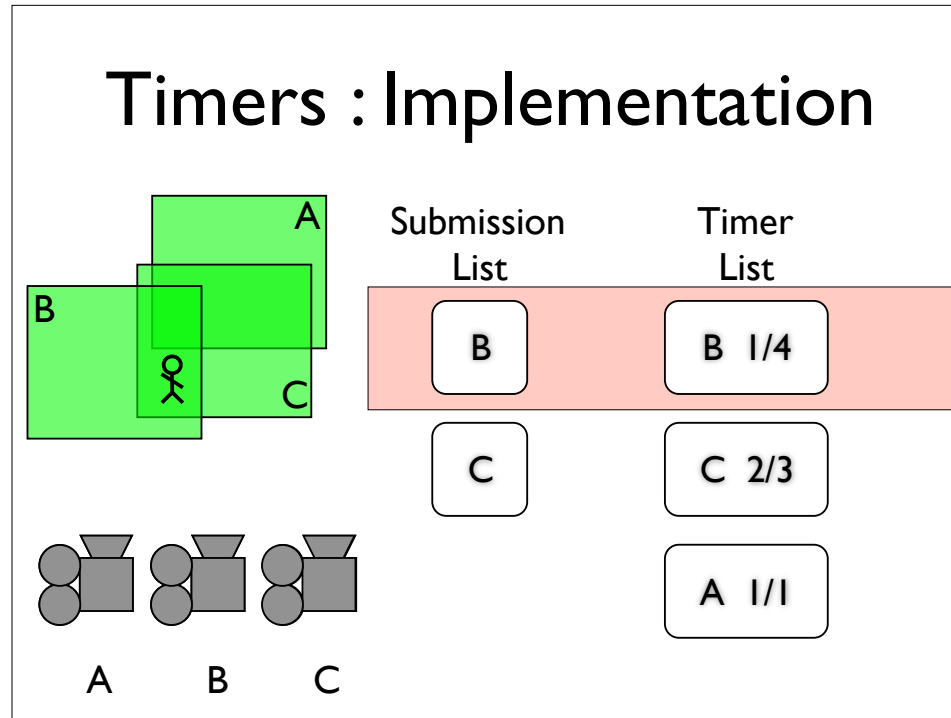
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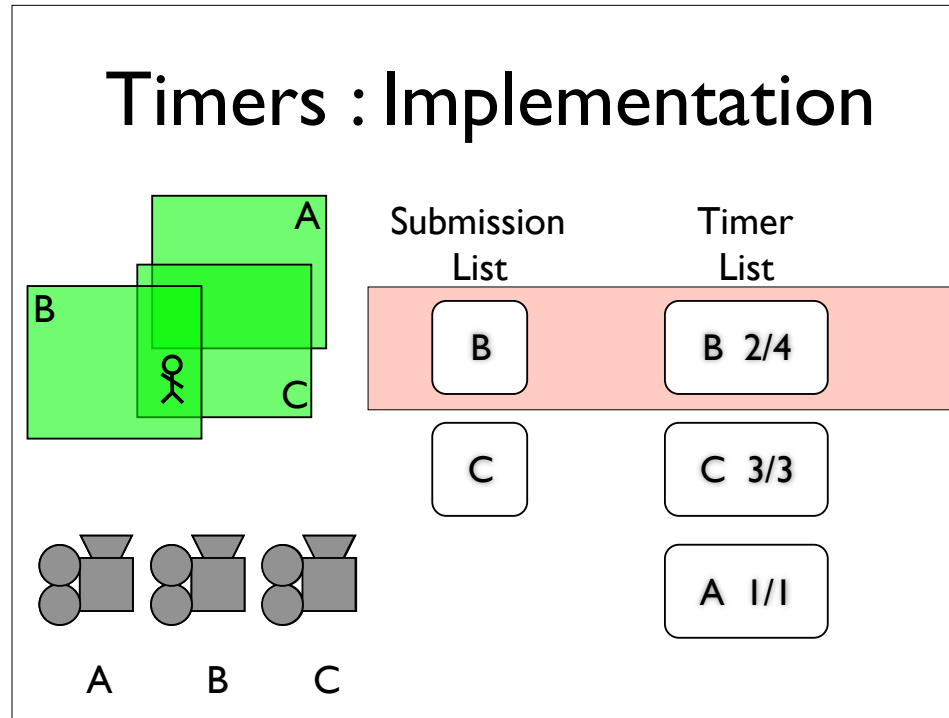
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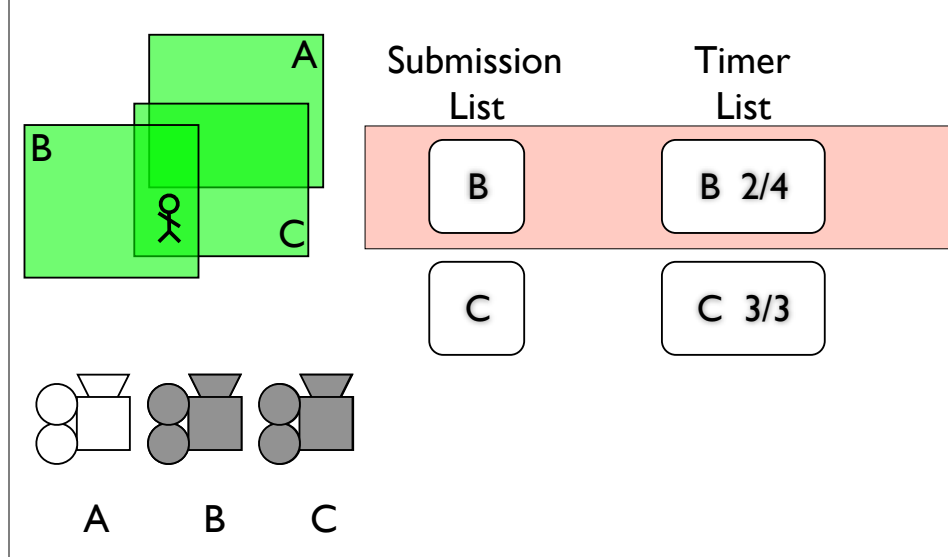
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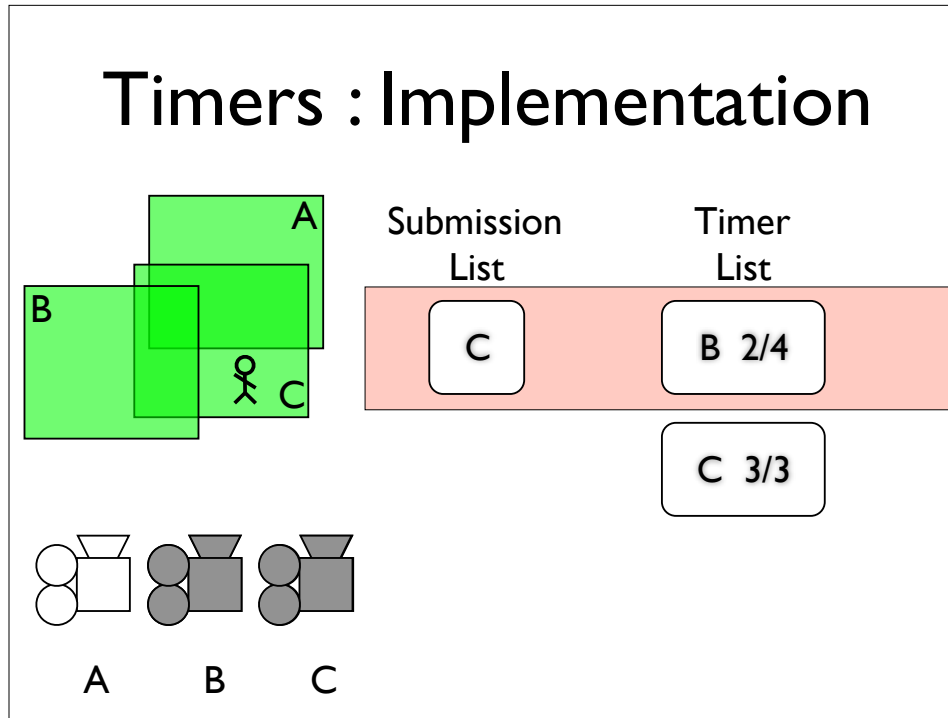
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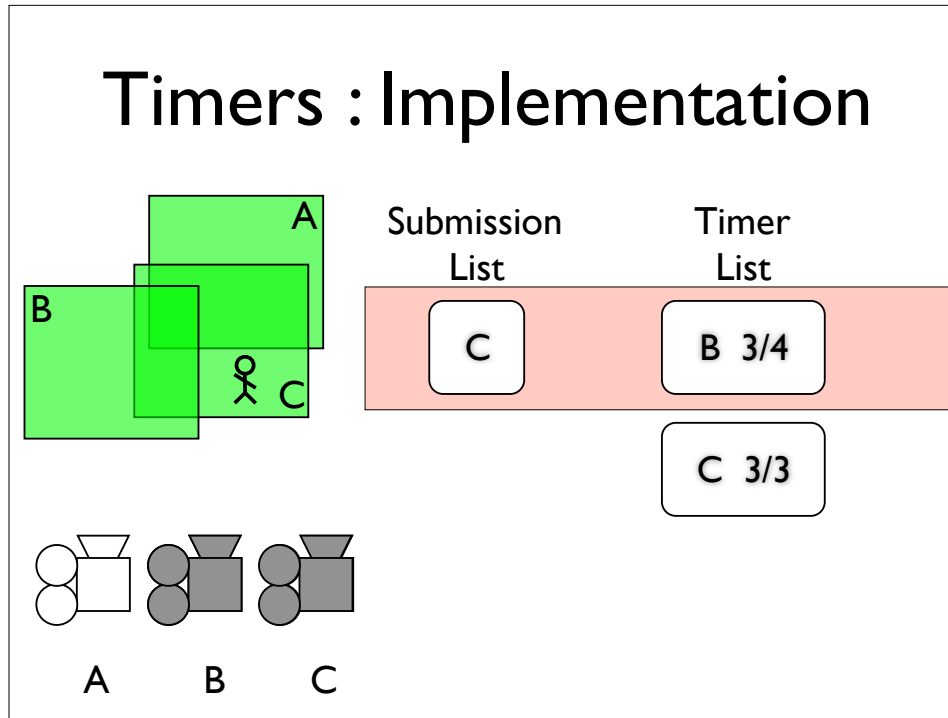
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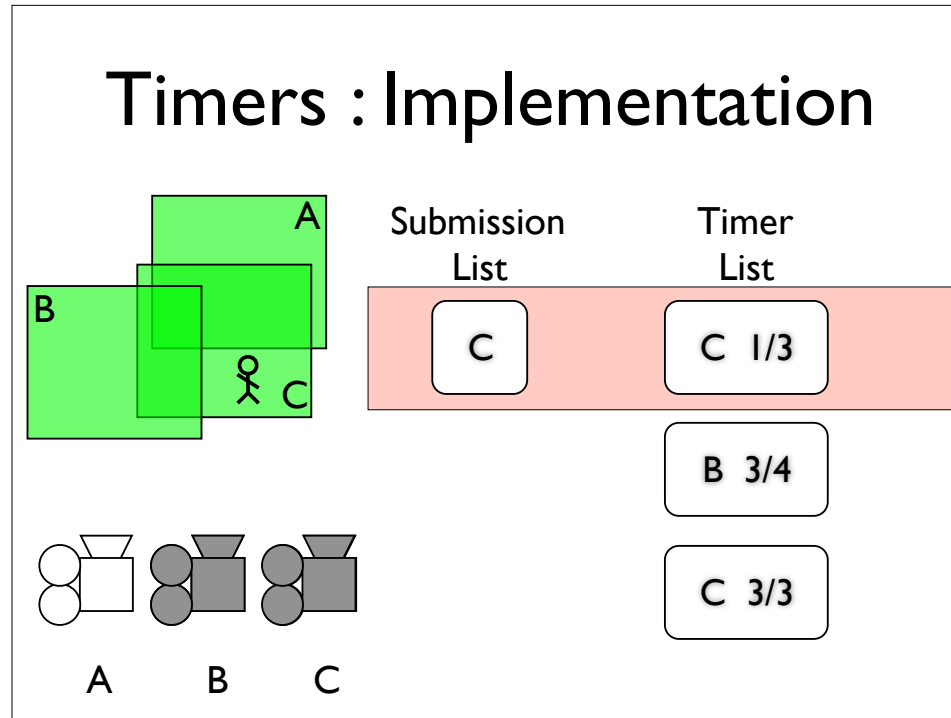
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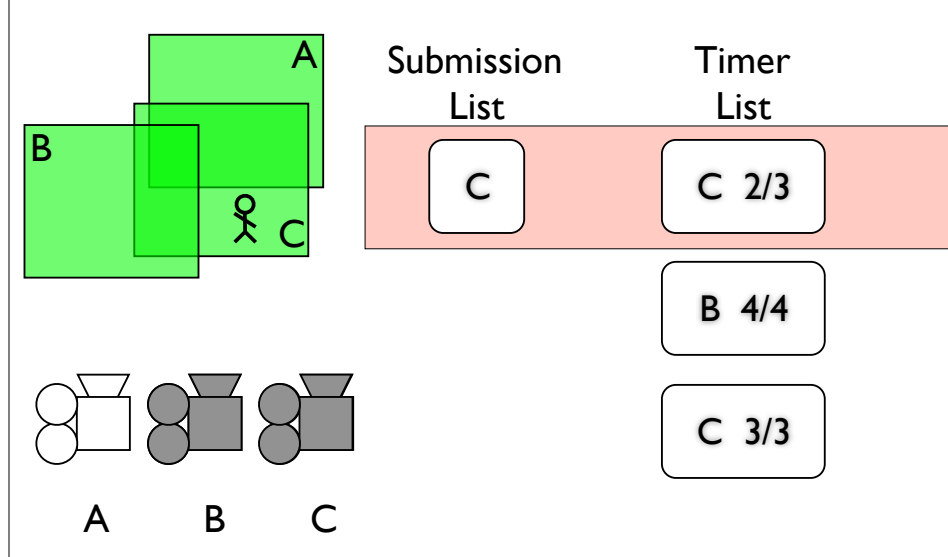
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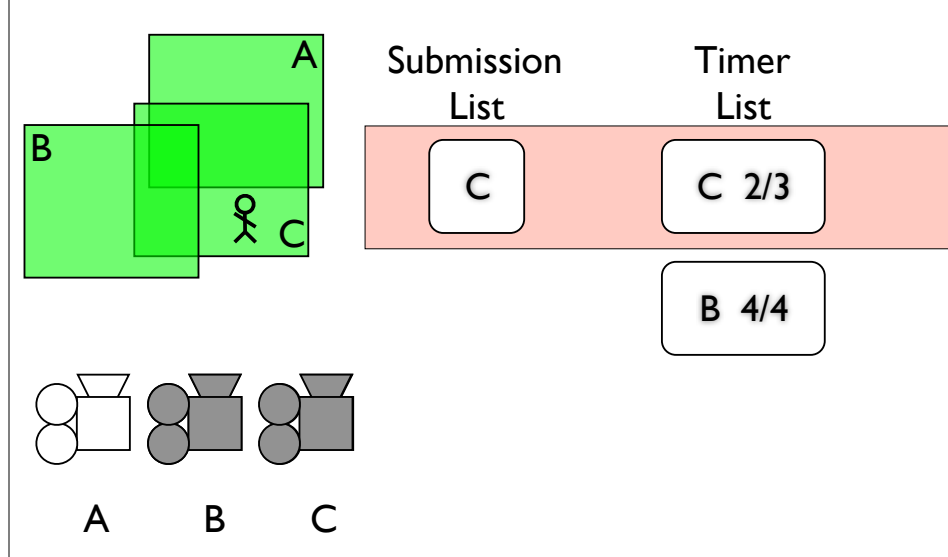
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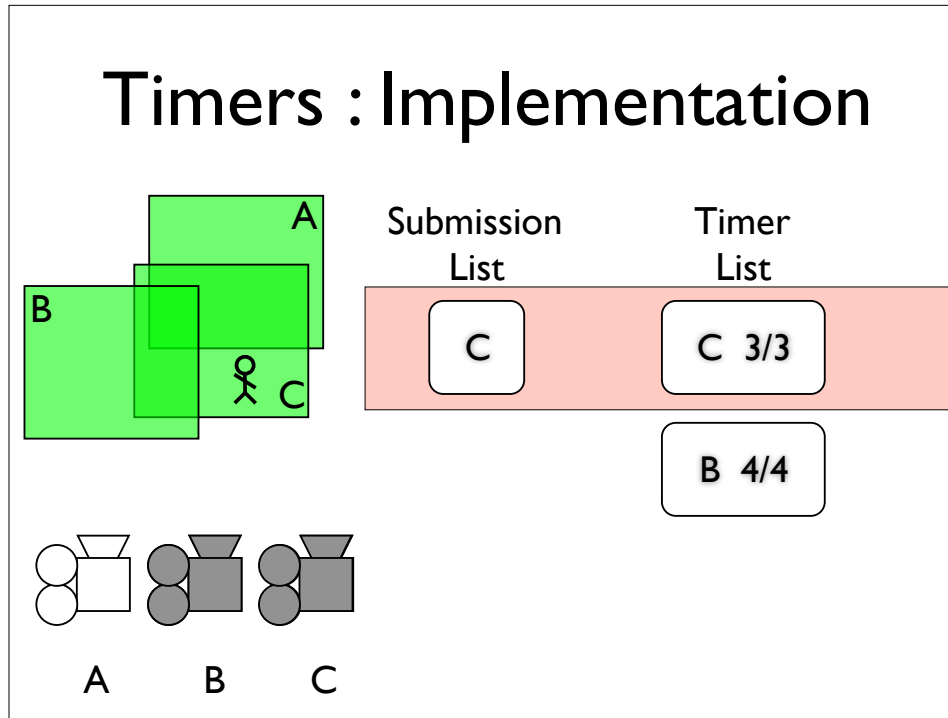
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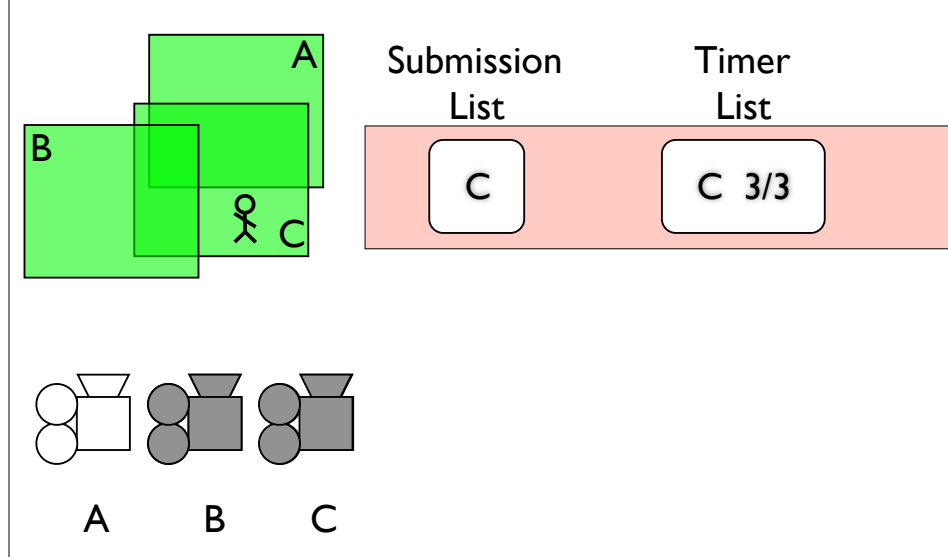
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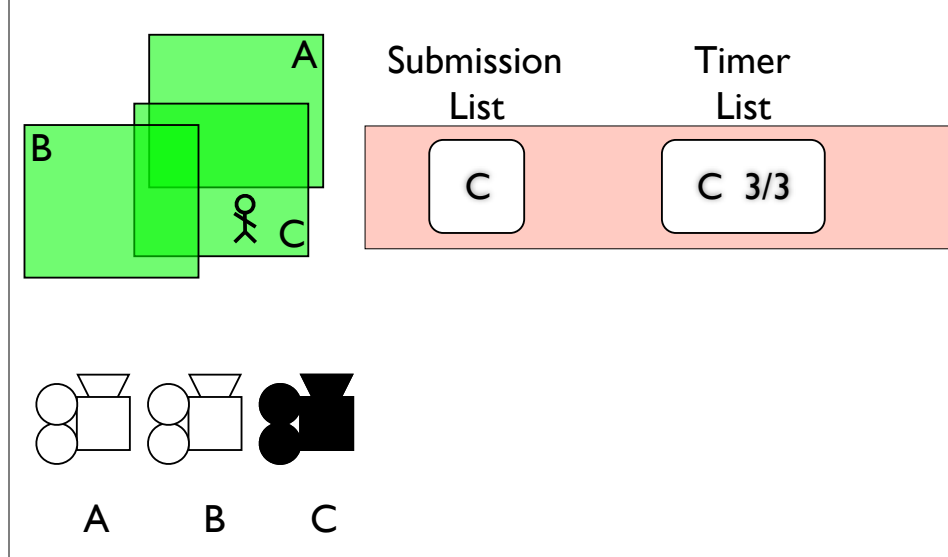
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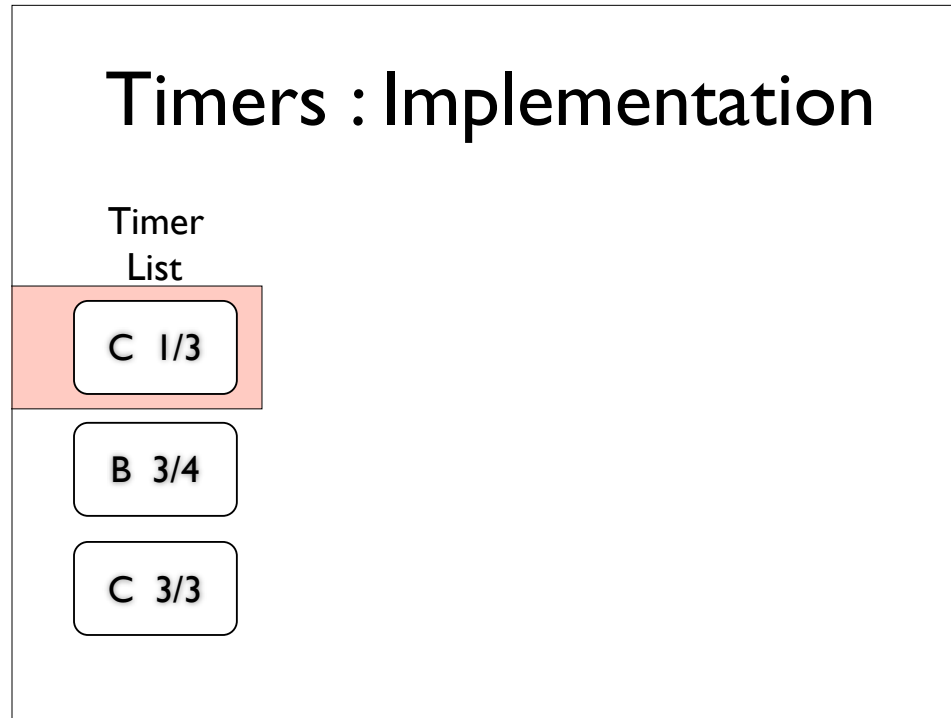
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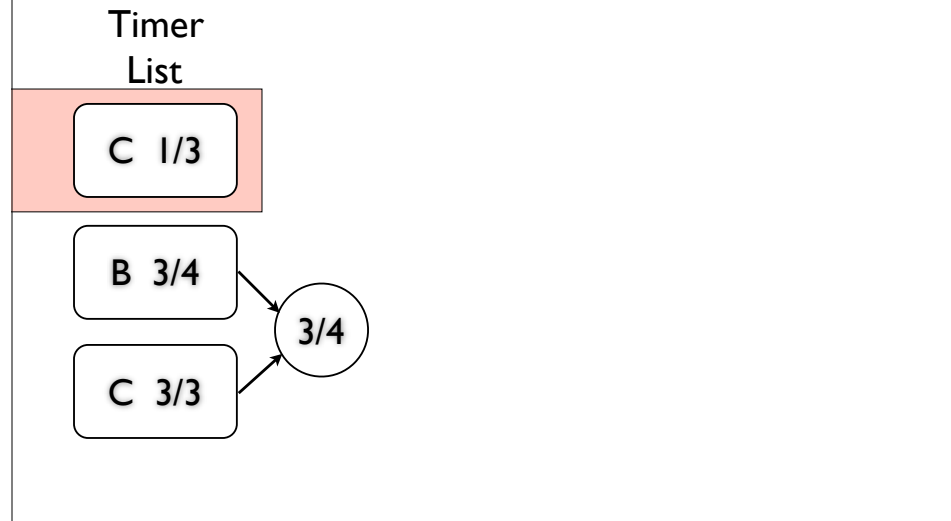
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Next we take the result, and blend that with the next newest camera, the top camera c, using, the new cameras timer. It's 1 second in out of 3, so 1/3 of camera c, and 2/3 of the previous blend which ultimately works out to be 1/2 camera b and 1/2 camera c

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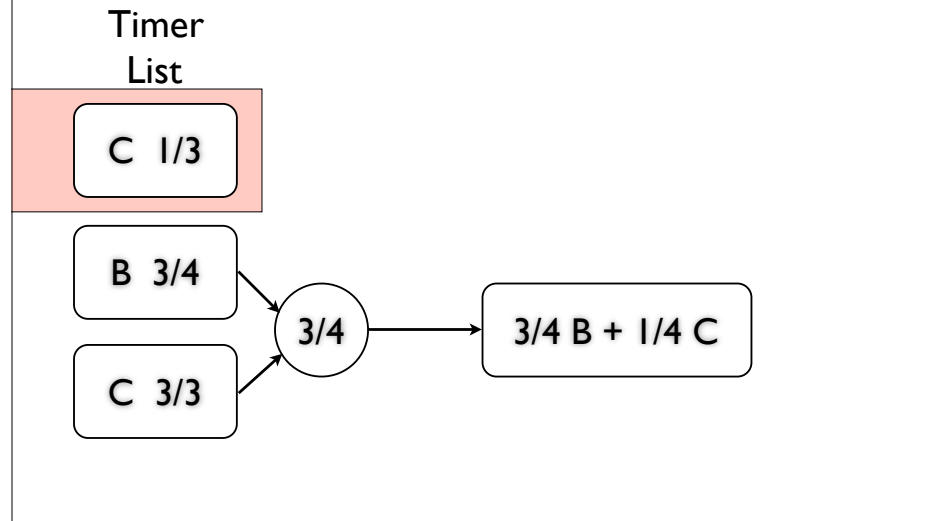
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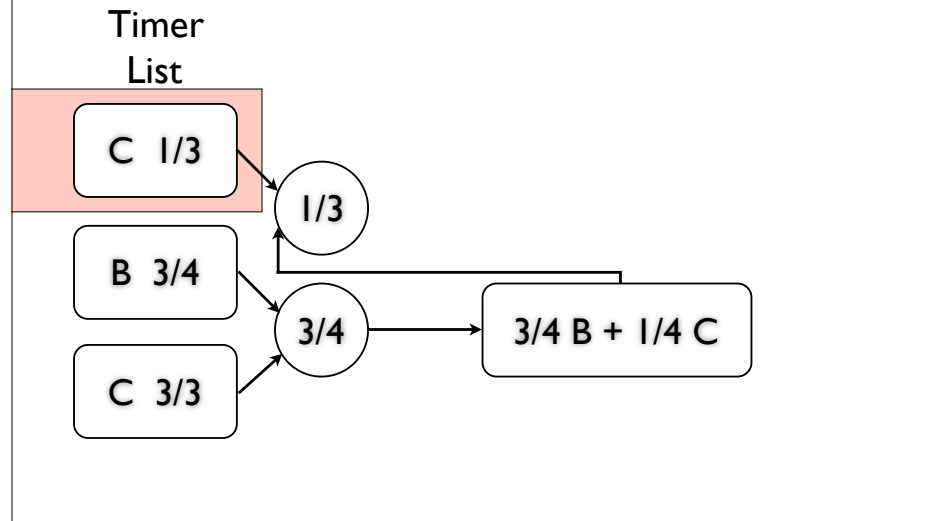
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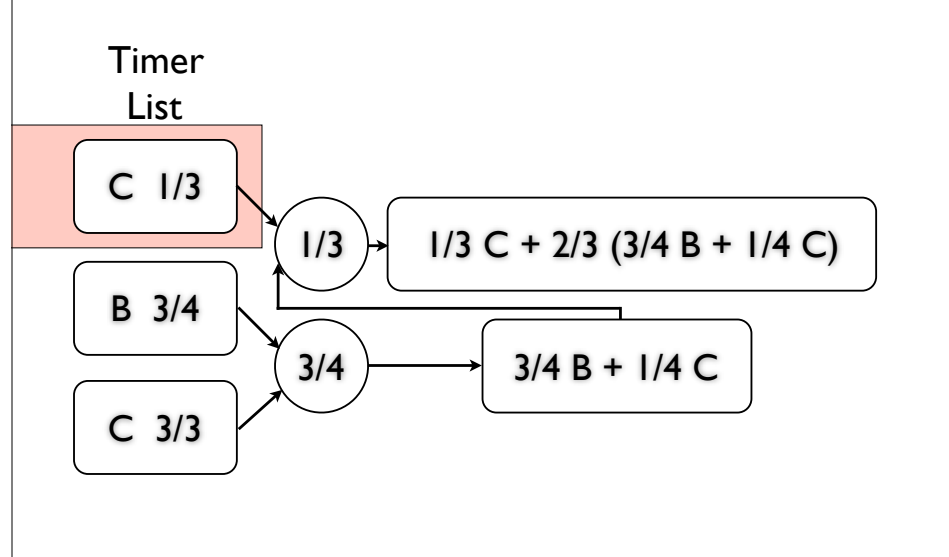
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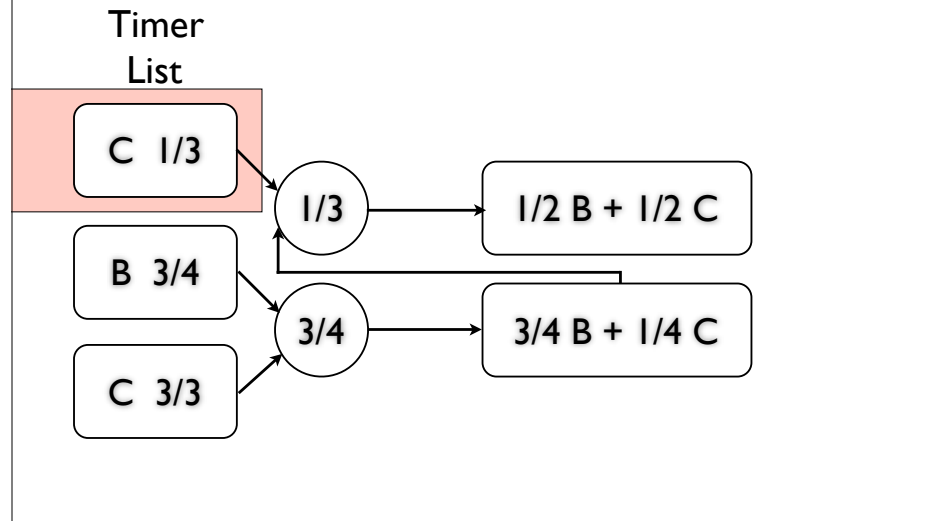
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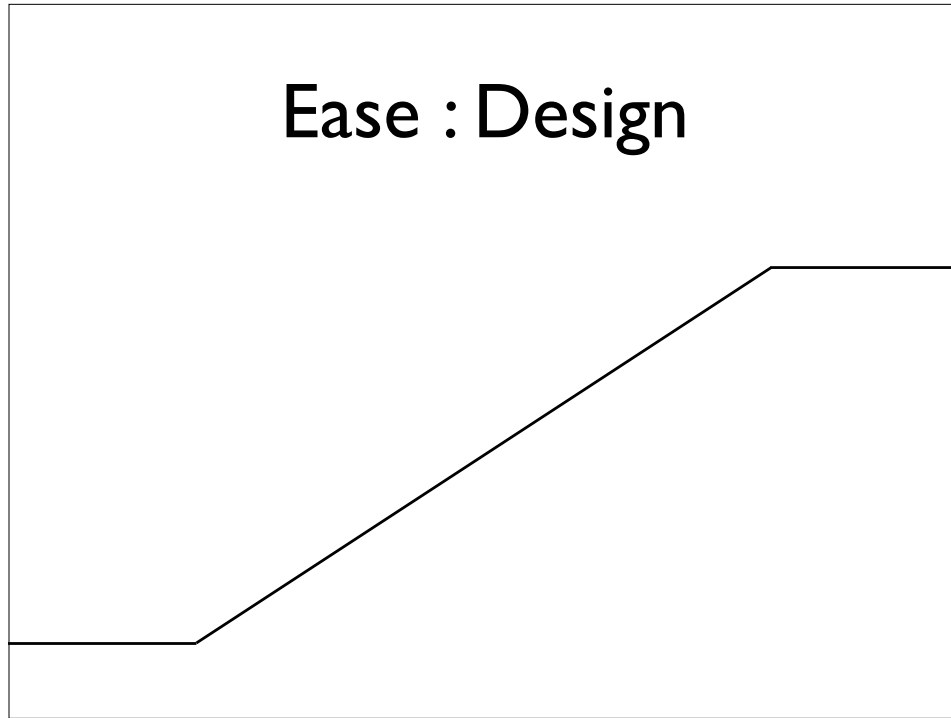
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Ease : Design

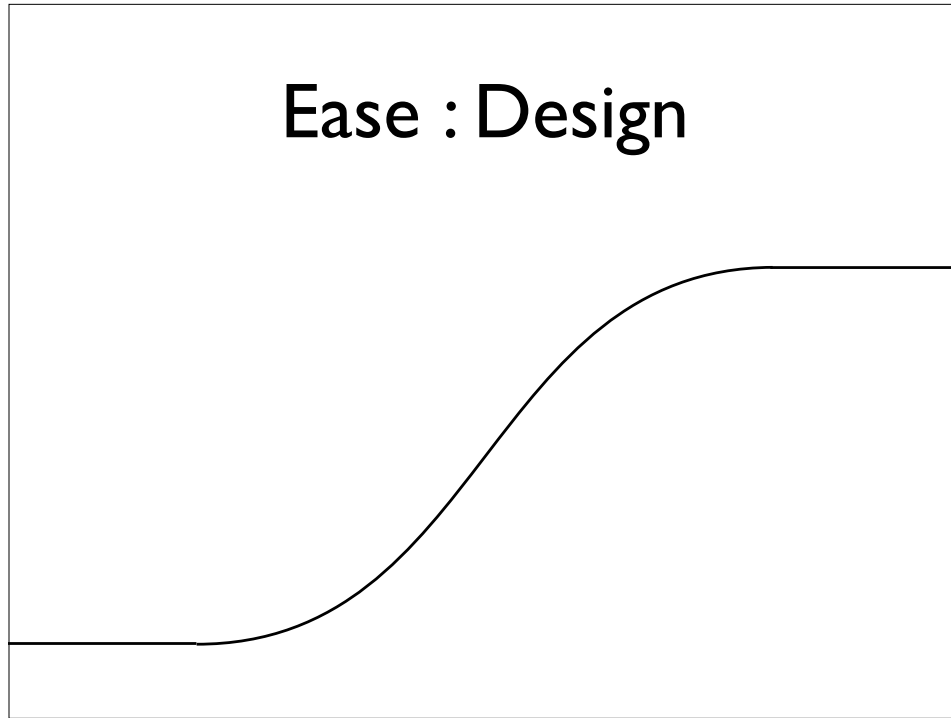


The trouble with using the timers raw, is that you get these **simple linear blends**. You can see the **sharp corners** here, and when you use them to blend cameras, you can see the jerk as it starts to move, and again when it stops. While sometimes this is desirable, mostly it's just ugly.

What we want, is to add what animators call "ease".

To do this, we feed the linear blend, into a spline.

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Ease : Implementation

- Hermite Spline
- Fixed endpoints at 0 & 1
- Controllable tangents
- $\text{ease} = 1 - \text{tangent}$
- Ease in and out

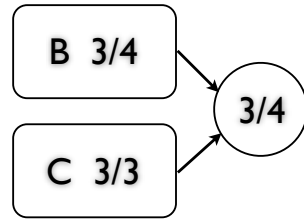
Specifically a Hermite spline, which lets you control the position and tangent of the endpoints of the curve.

We fix the endpoints at 0 and 1, and map the tangents into a range that makes sense as an 'ease' control.

With 1 representing full ease, 0 no ease, or linear, and -1 giving us negative ease, for those special times when you need a really harsh blend.

We allow the designer to control ease in and out separately.

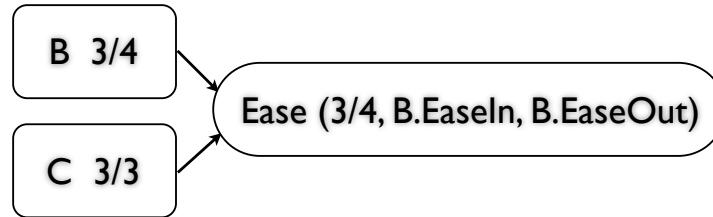
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We apply ease when we calculate the blend factor between two cameras.

We take the timer, and feed it into the ease function, which just evaluates the hermite, taking ease in and out values from the new camera.

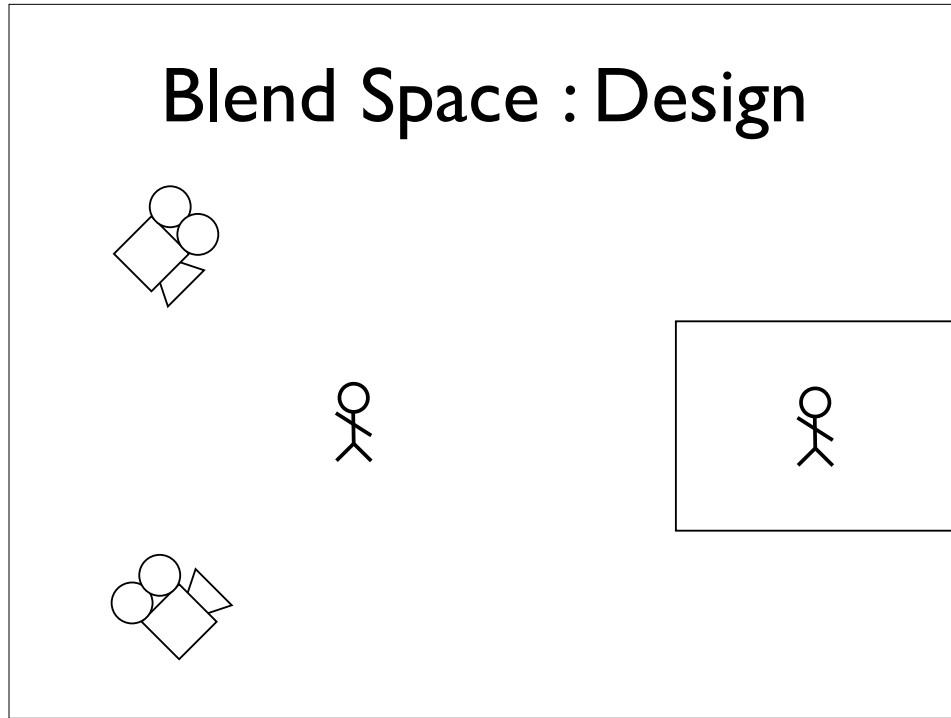
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Blend Space : Design



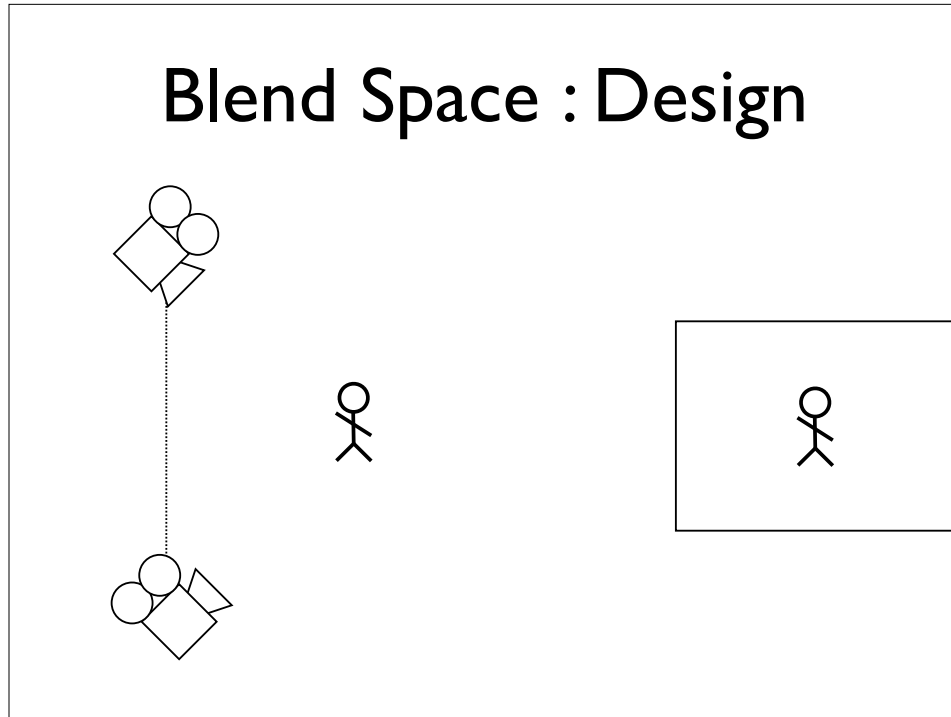
There's a hidden problem in what we have described so far for blending.

???

If we blend **positions** (not talking about proportions here) along a straight line, we get "blooming" effect.
(animate 4 clicks to demonstrate)

Solution: Blending positions along a circular arc of fixed distance from player.

Blend Space : Design



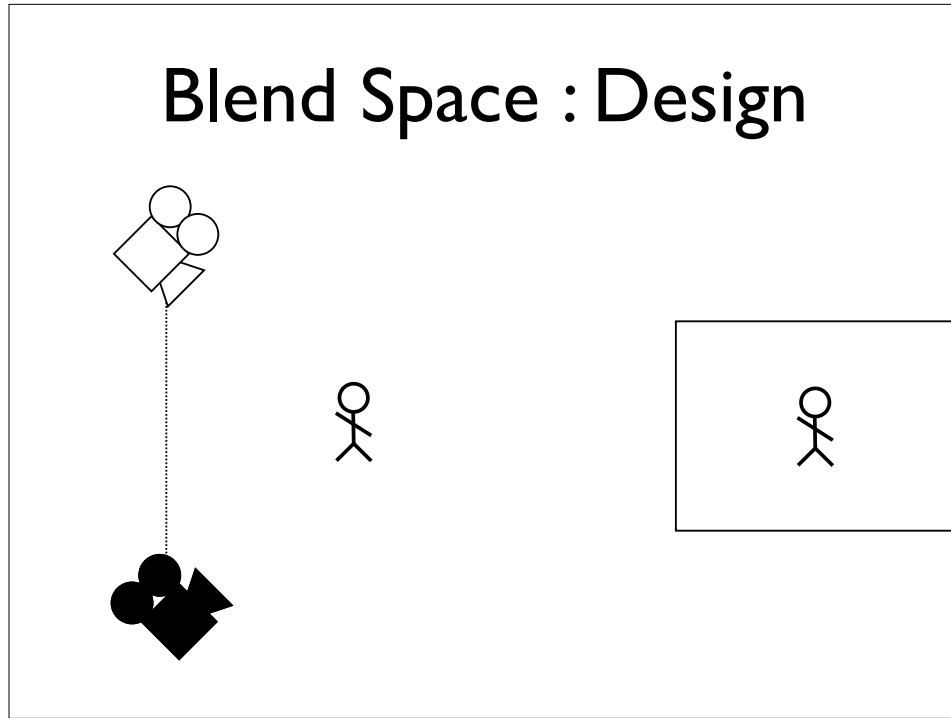
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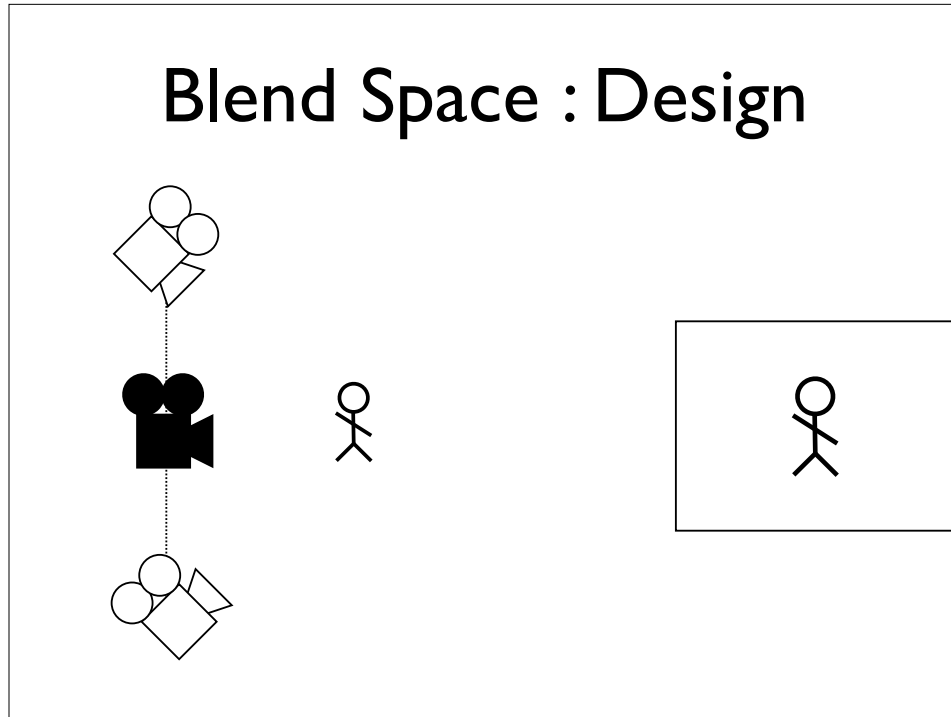
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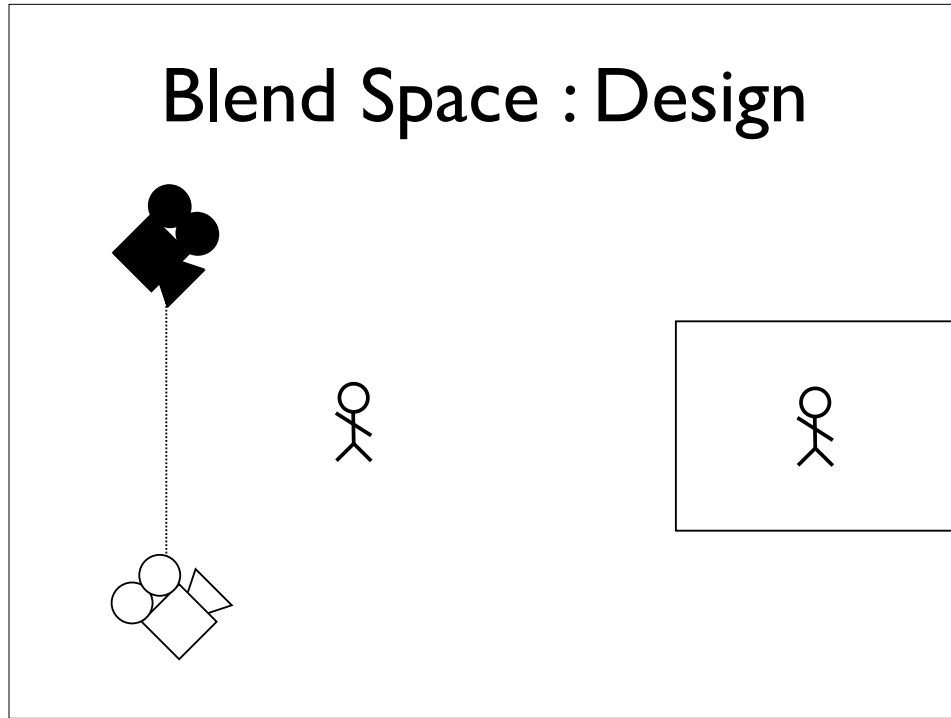
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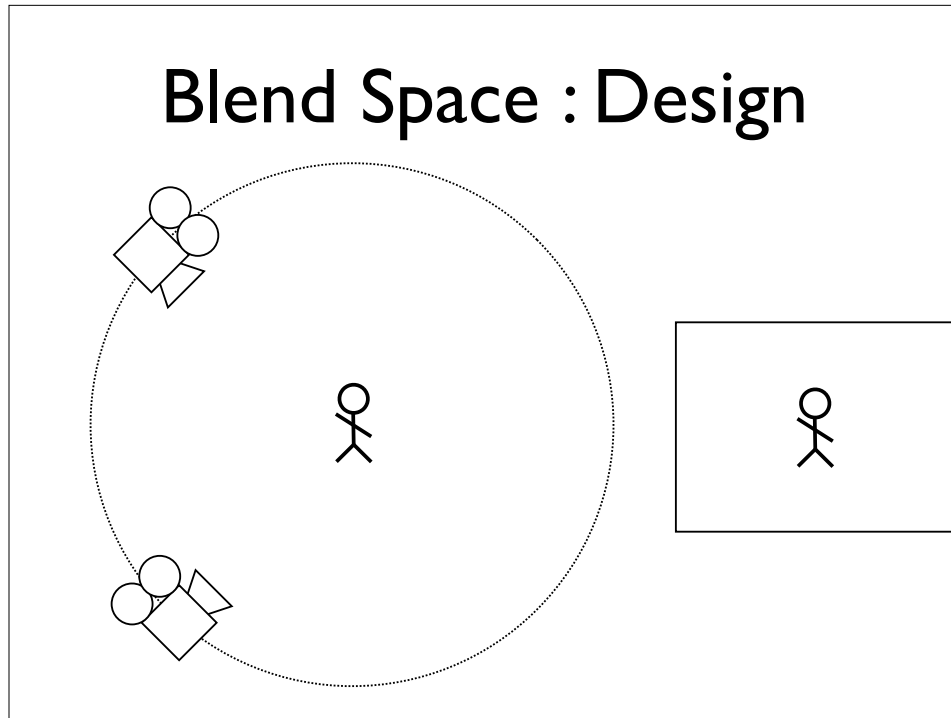


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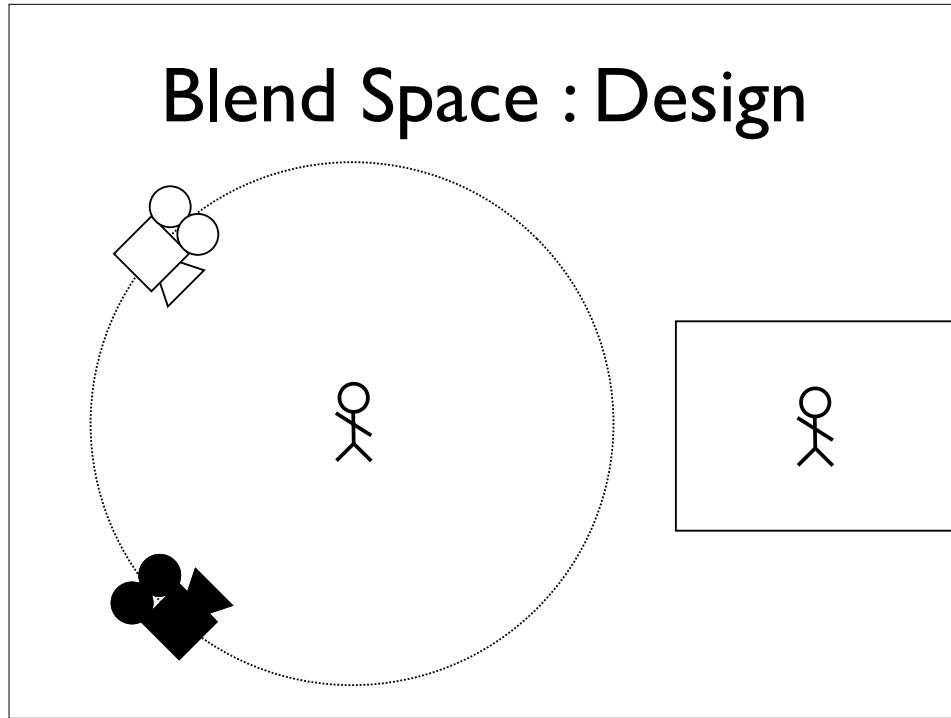
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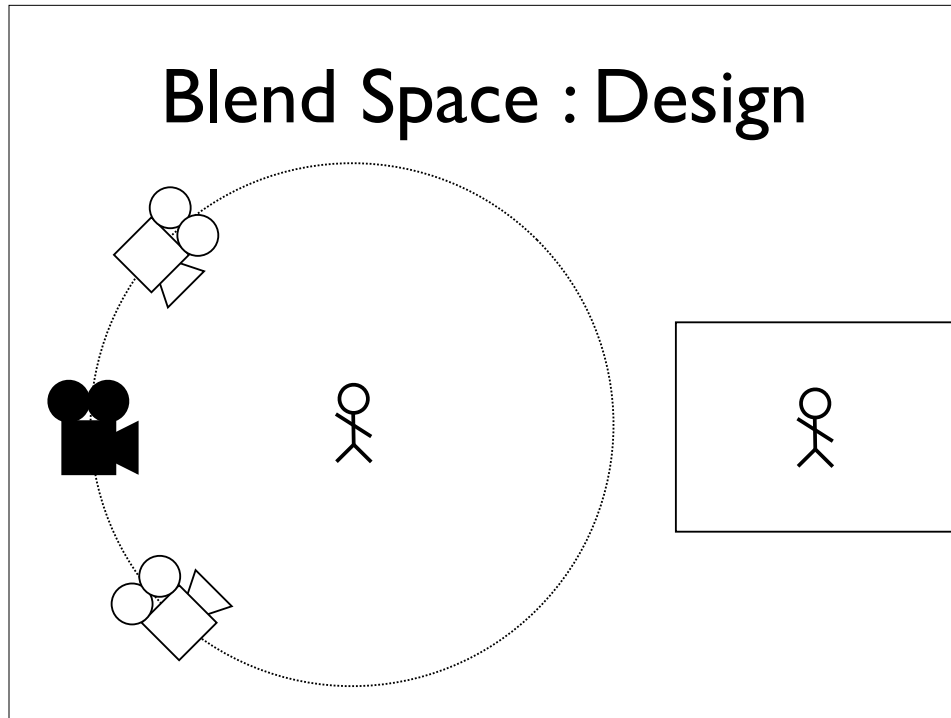


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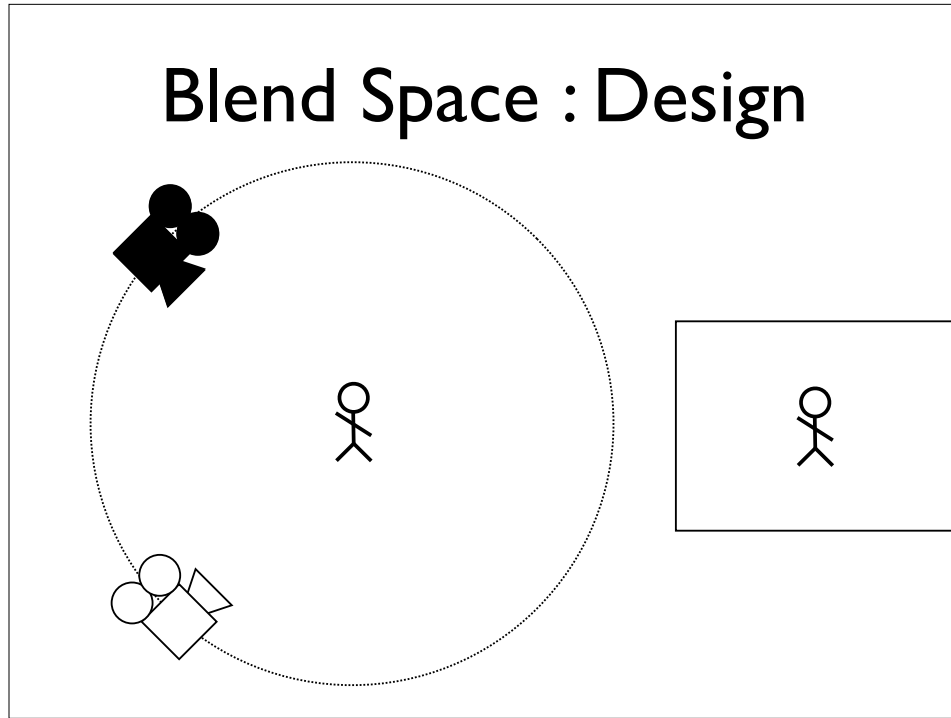
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Overview

- Zoning
- Dynamics
- **Blending**
- Rails

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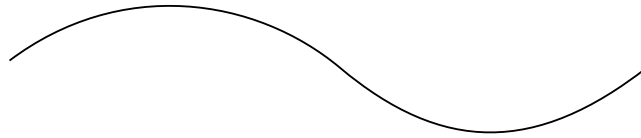
- Zoning
- Dynamics
- Blending
- **Rails**

Rails : Objectives



A generalization of this “camera track” idea is to borrow an idea from the film industry. One of their solutions to this problem, is to construct rails, and put the camera on a little cart, known as a Dolly, that rides on the rails.

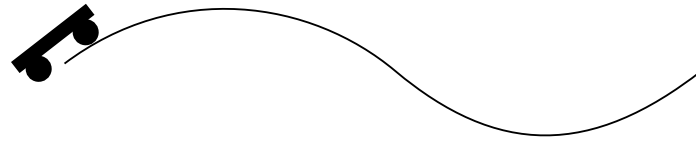
Rails : Design



Now for us, the rail is spline, specifically a NURB (constructed in Maya).

And the Dolly is a point on that spline, represented by the **parametric value** of the spline at that point.

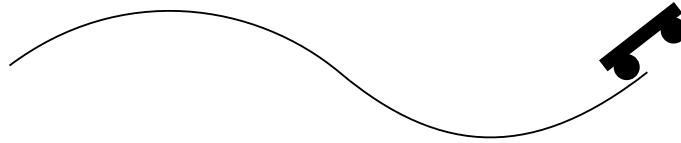
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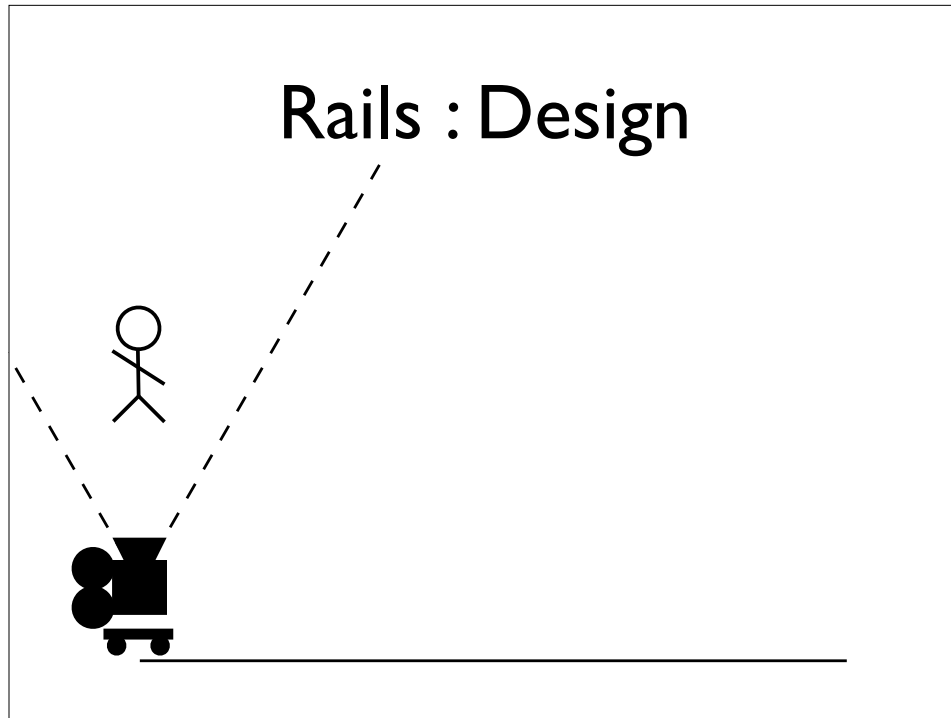
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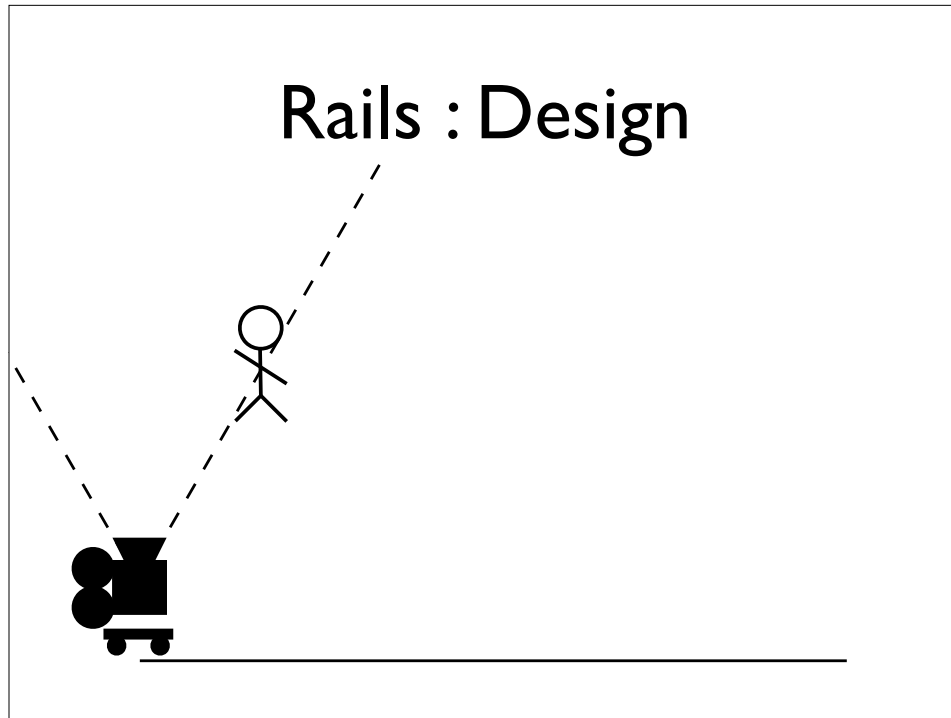
And the Dolly is a point on that spline, represented by the **parametric value** of the spline at that point.



So we have rail, we have a dolly on that rail, and we have the camera sitting on the dolly.

What we want to do, is only move the dolly by enough to keep the player within the constraints defined by the camera.

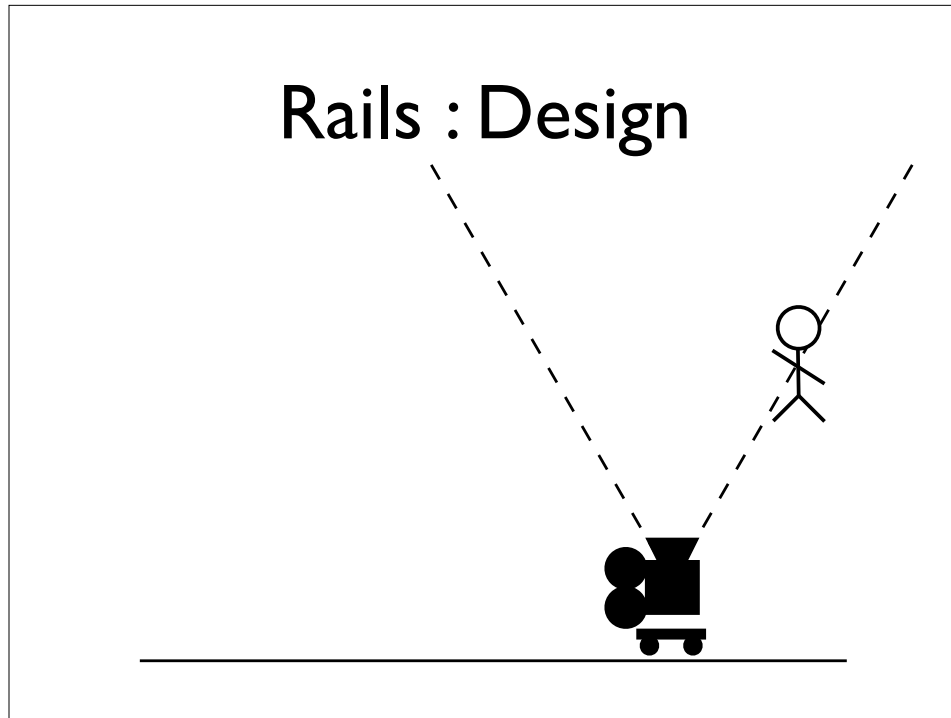
The player is free to move within the constraints, but when he tries to move outside them, the dolly moves to compensate as best it can.



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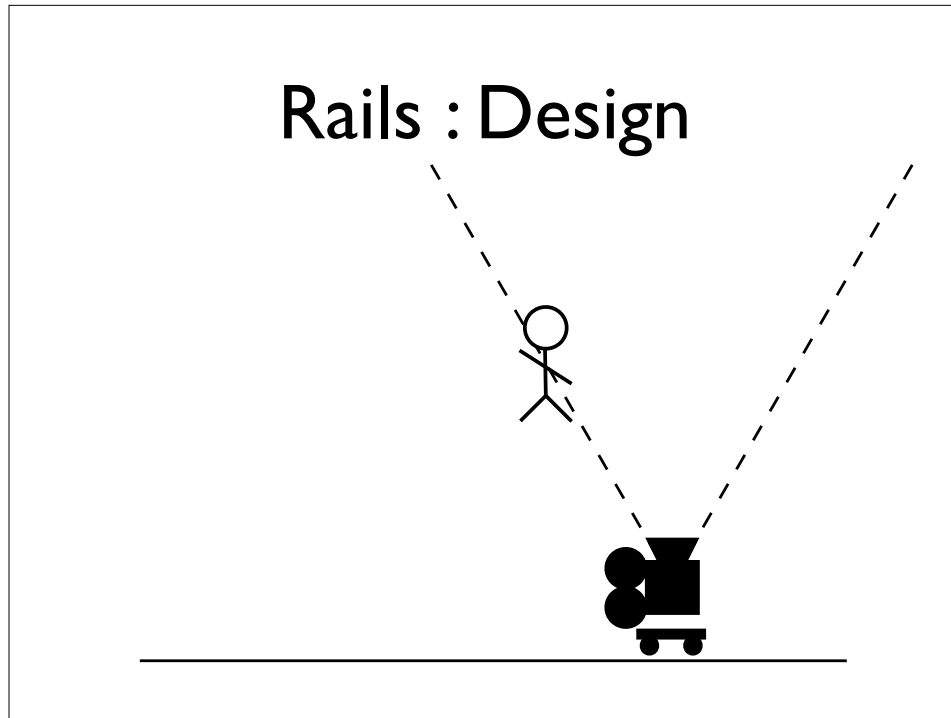
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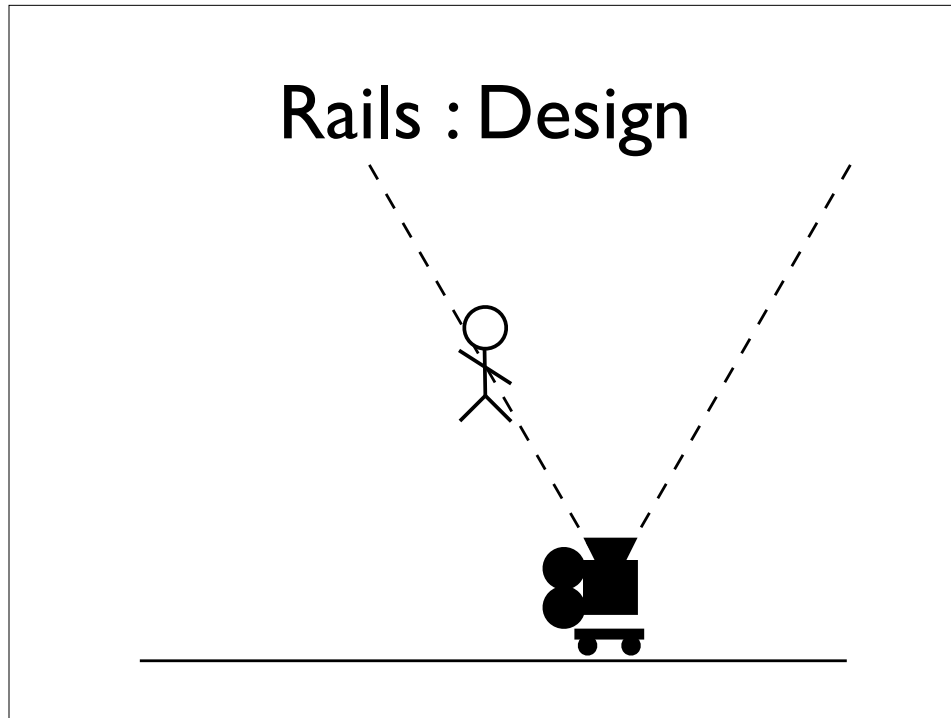
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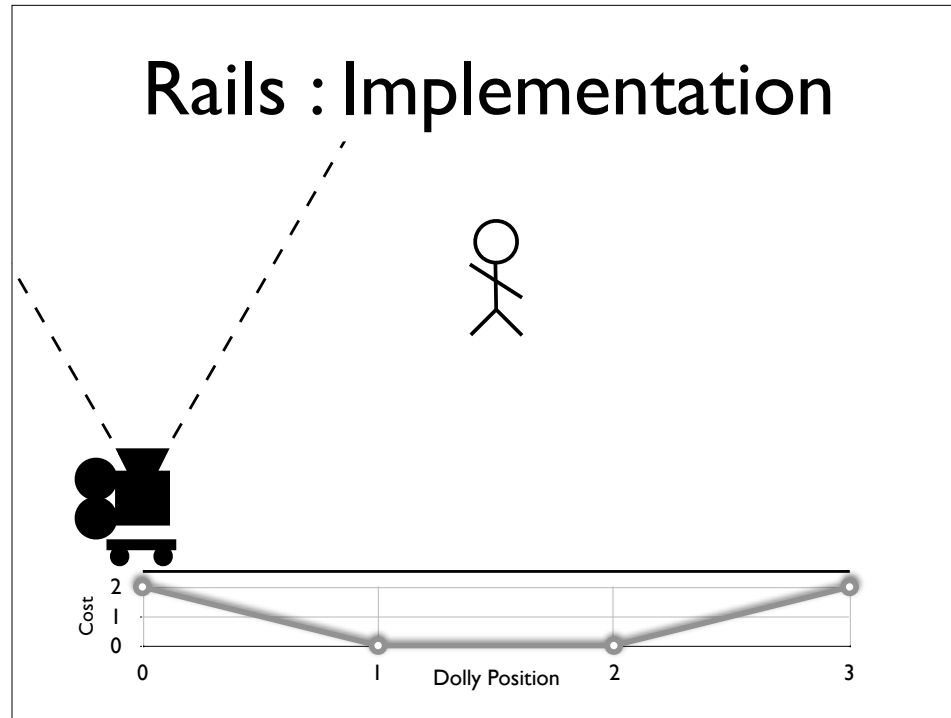


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Rails : Implementation



So how do we do that.

We'll remember that the Dolly is actually just a point on the spline represented by a single parameter.

We use the constraints to calculate a cost at a given point on the spline.

Here we see that the player is 2 units outside of the constraint, so the value of the cost function at this point, zero, is 2.

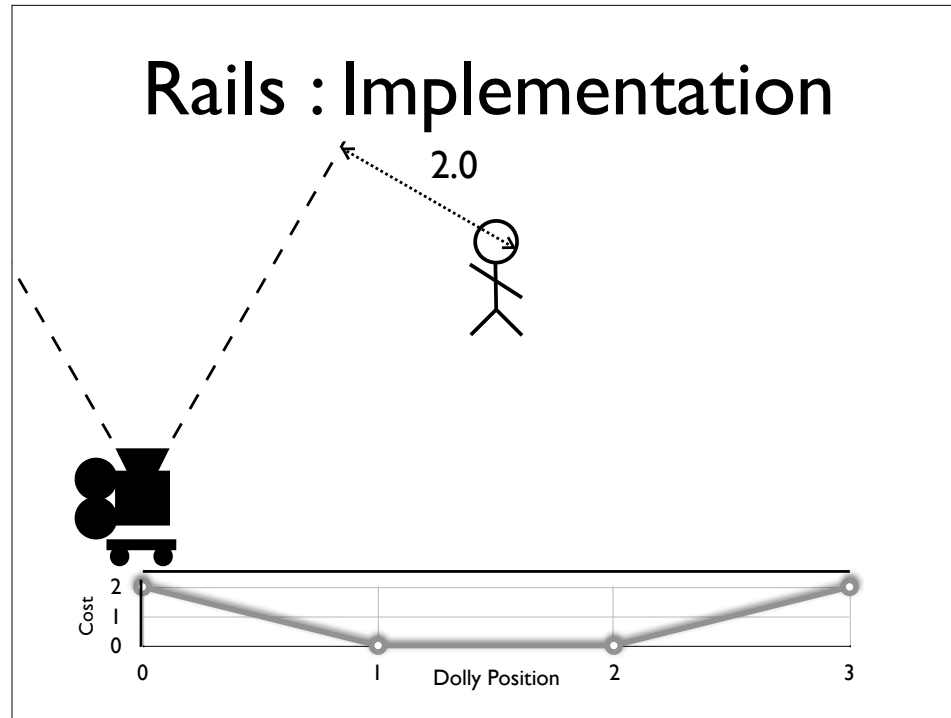
If we move the dolly to position 1, the player is just inside the constraints, and so the cost is zero.

Between positions 1 and 2, the cost remains zero, as the player remains inside both constraints.

And as we move to position 3, the player is now 2 units outside the other constraint, and the cost is 2 again.

So, armed with this cost function, what we're actually trying to do, is find the **nearest minima** on it, to the previous position of the dolly.

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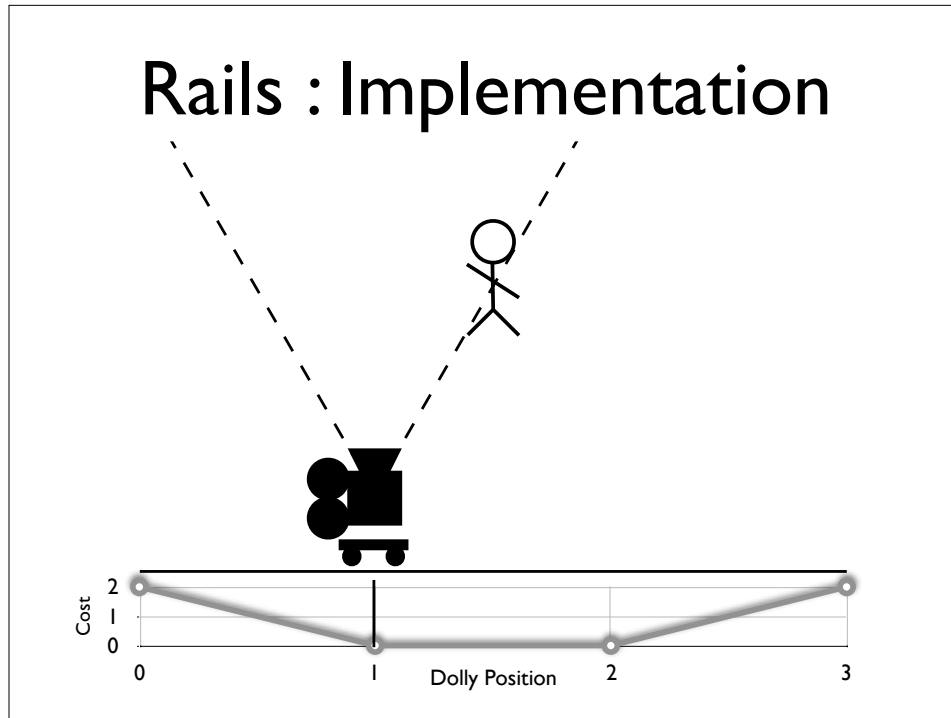
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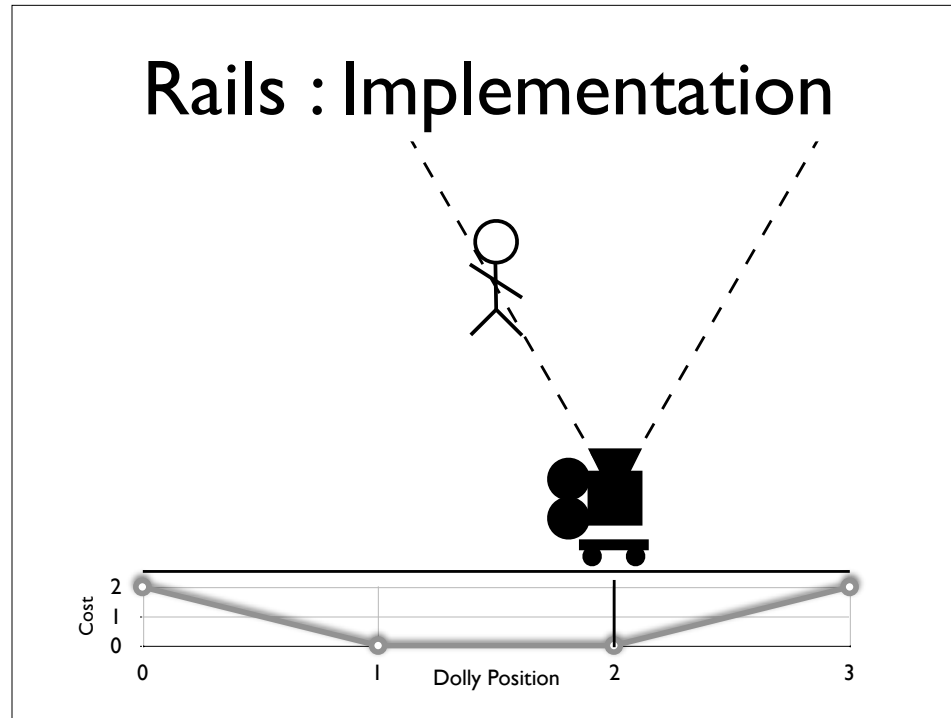
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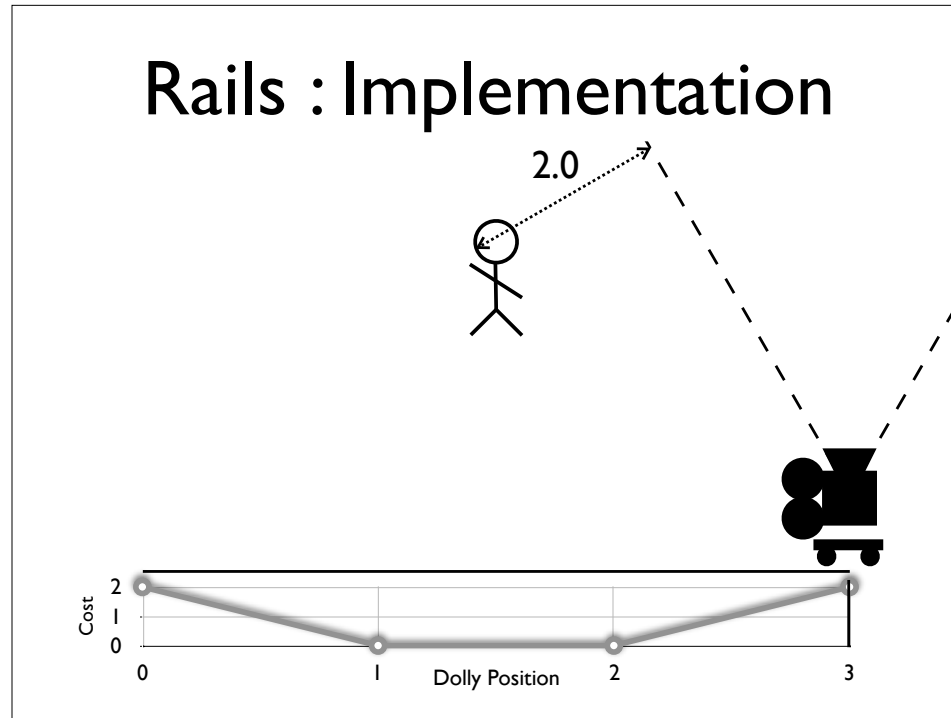
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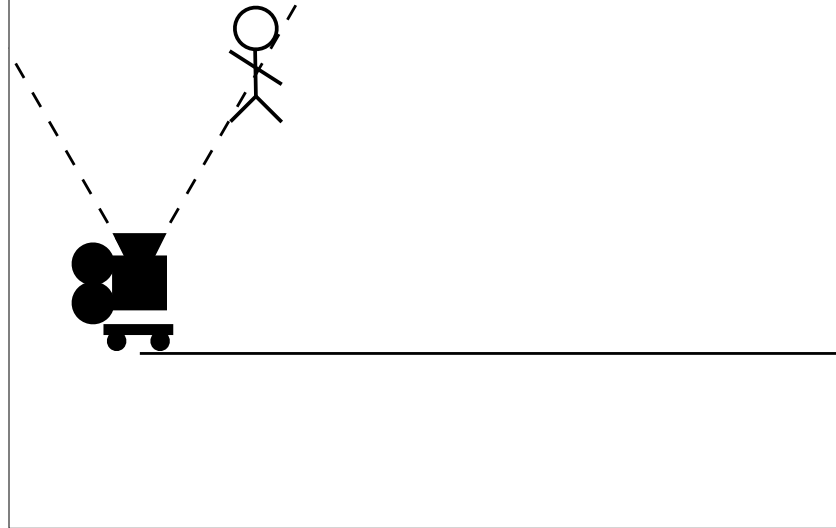
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Rails : Implementation



In this example, the player moves outside of the camera's constraints. Which gives us these costs.

In order to help us find the nearest minima, we add the distance from the Dolly's initial position to the cost function (essentially penalizing for moving farther)

...and now the weights look like this.

Now there are a number of ways to locate the minima, but this is how we do it (classic **hill-climbing**)

We take a guess as to which direction the player has moved, and take an experimental step in that direction.

If the cost at the new position is lower, then we try another step.

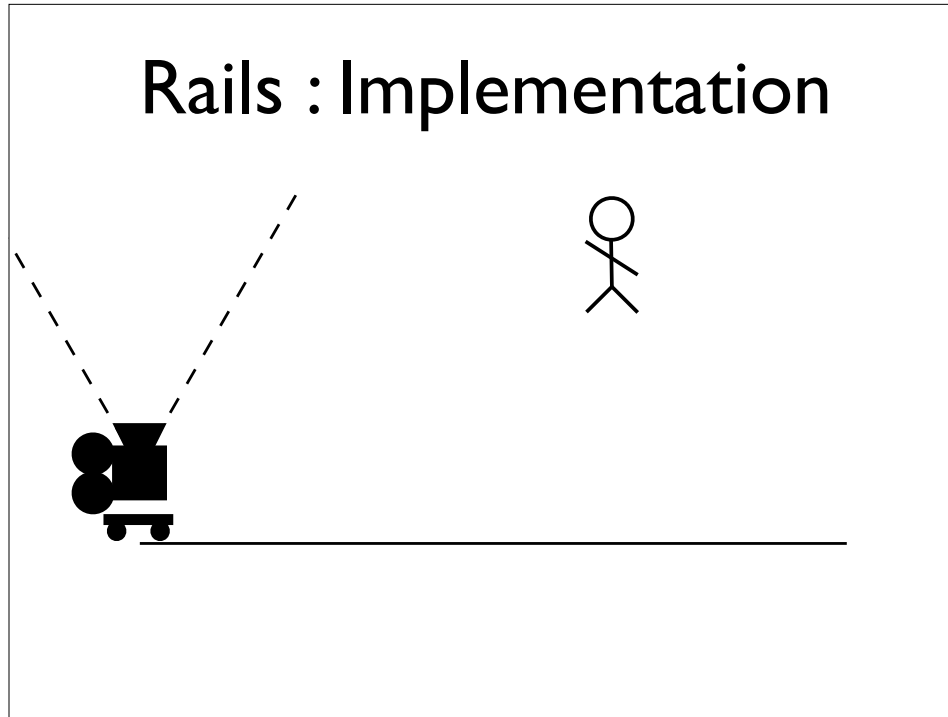
If the cost is higher, then we turn around slow down, and go back.

If as a result of slowing down, our next move is below a certain threshold, then we stop.

The smaller the threshold, the smaller the potential error, the smoother the camera, but also, the more times you'll evaluate the cost function.

Note: This method does NOT require calculating the derivative of the cost function.

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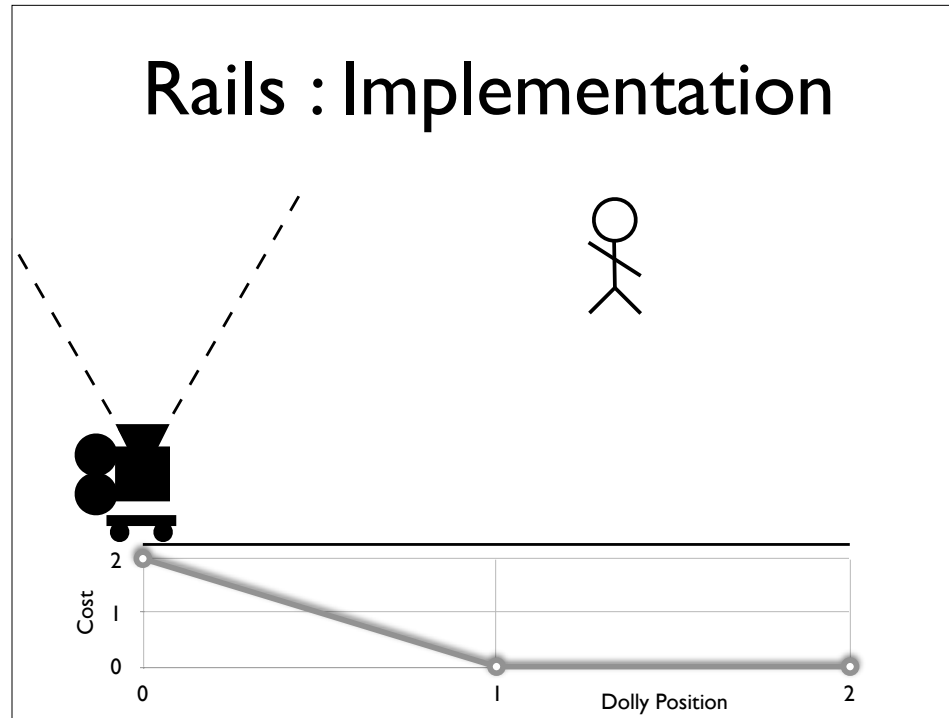
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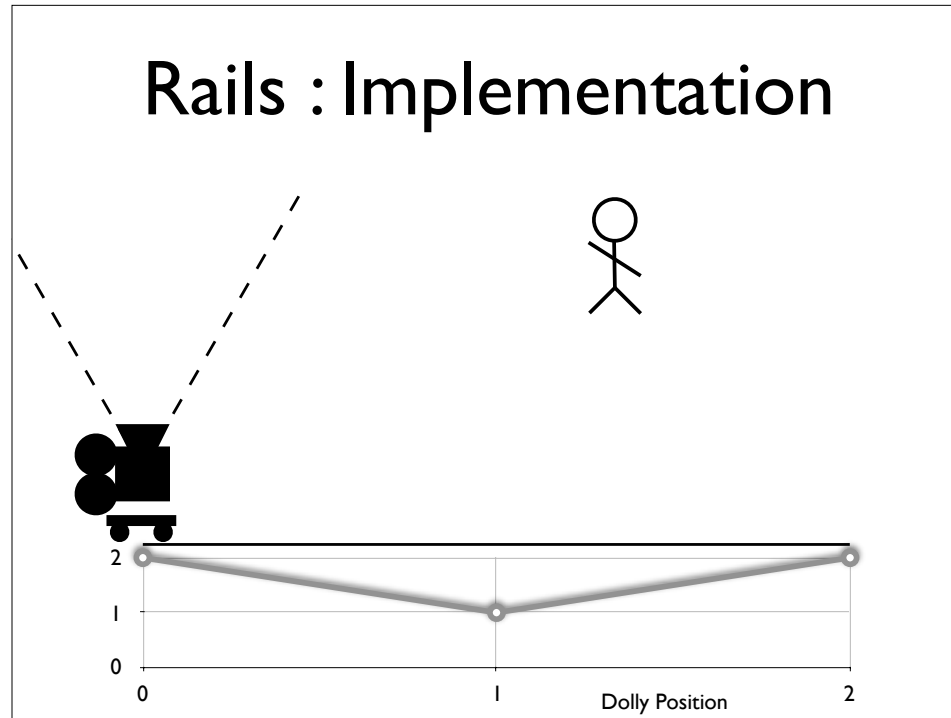
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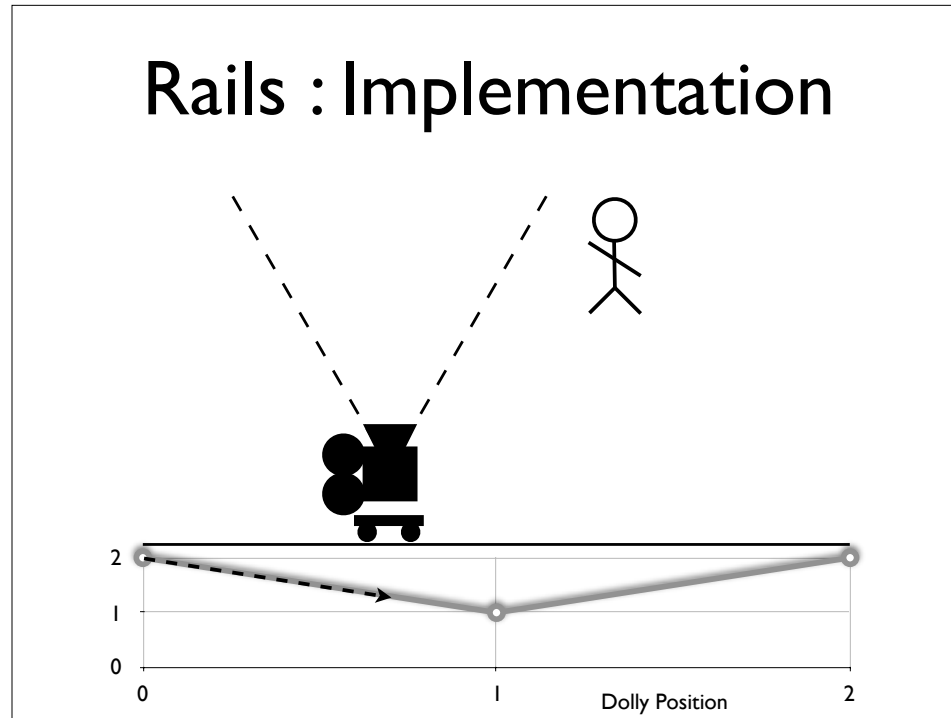
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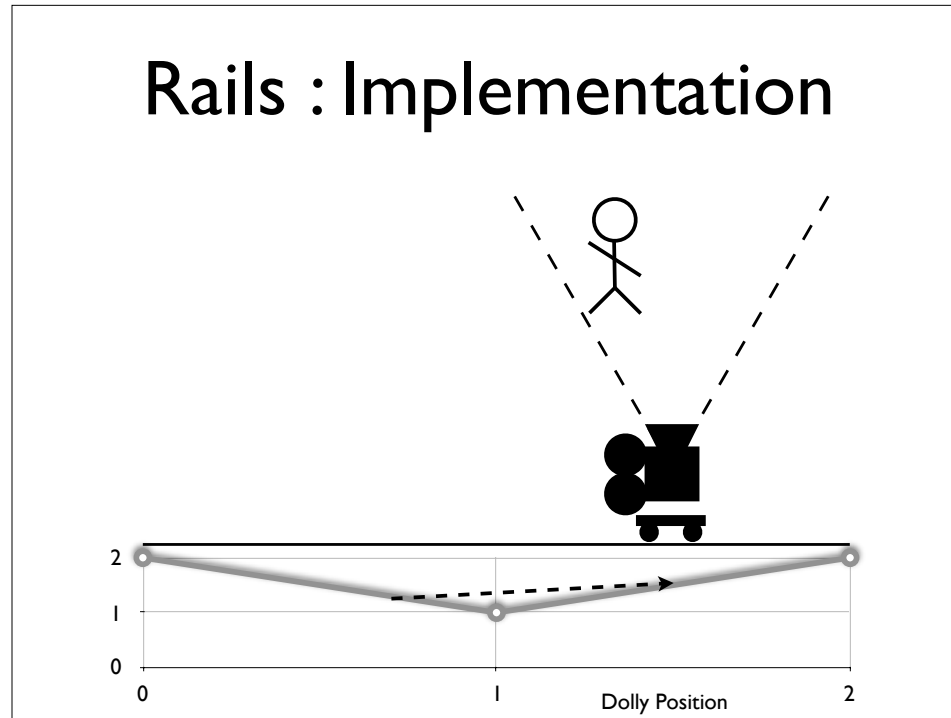
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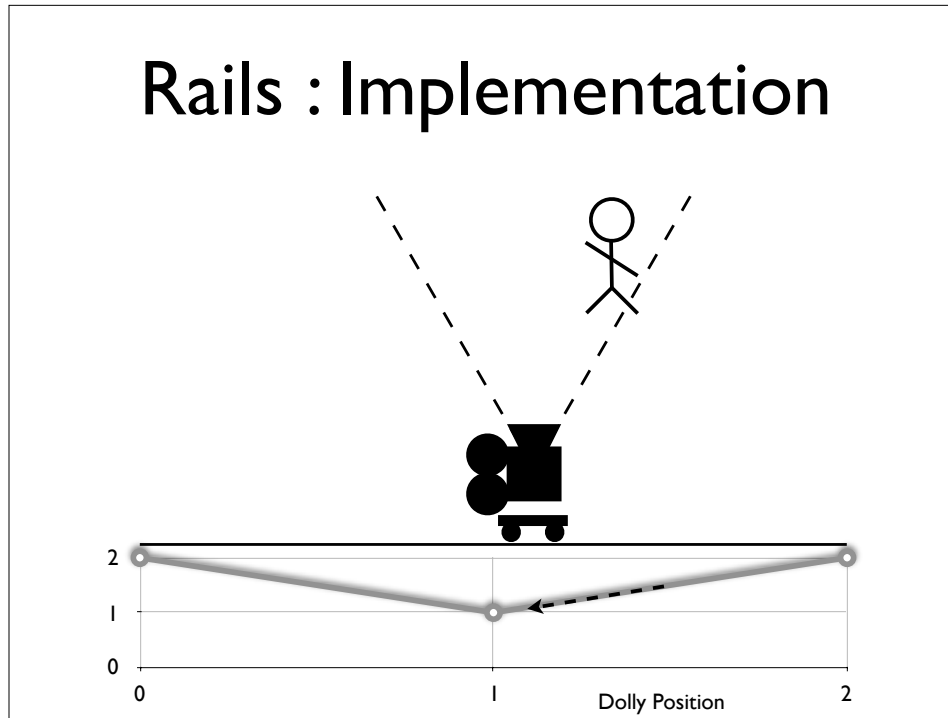
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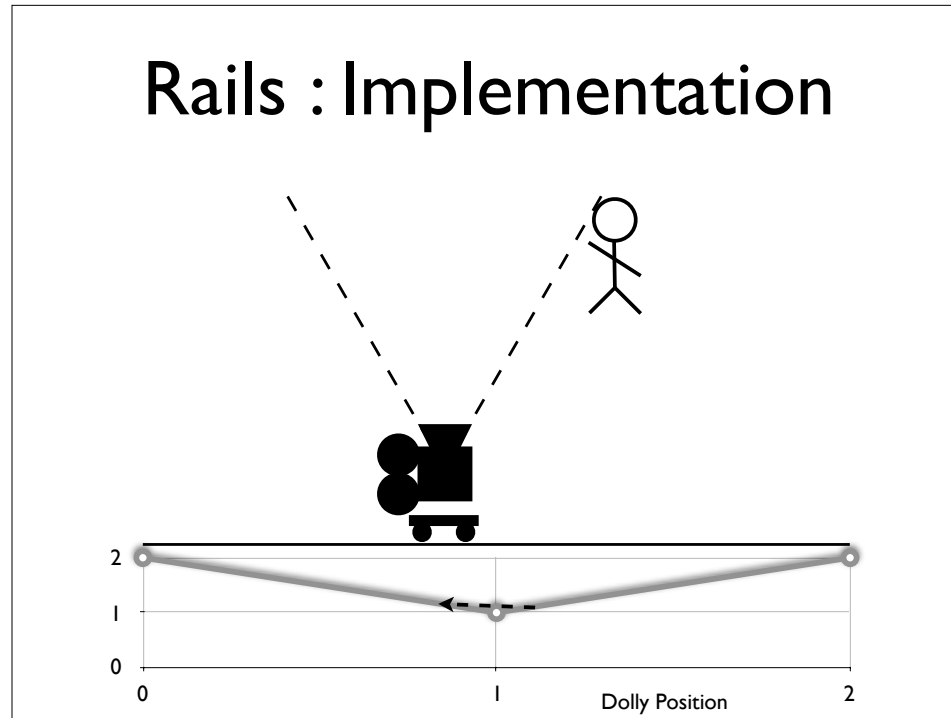
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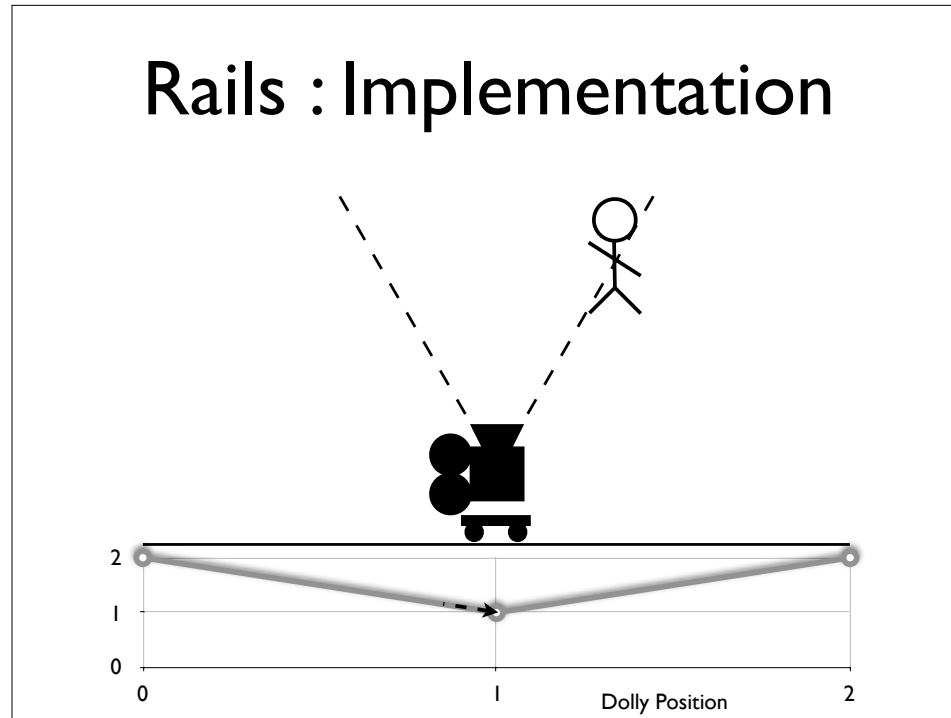
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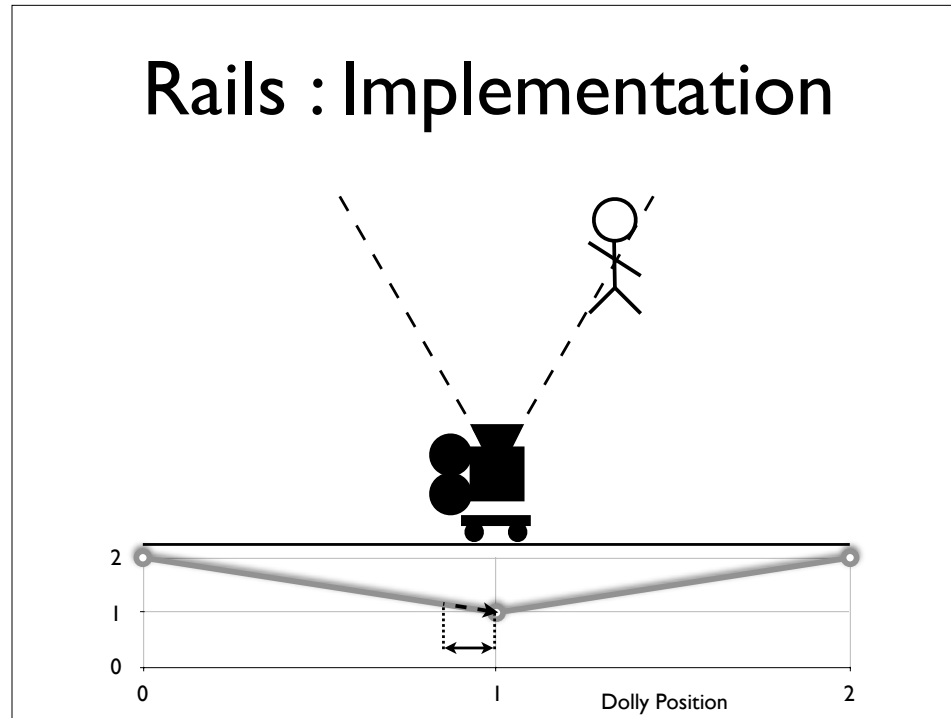
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Rails : Implementation

- Additional Costs
 - Distance from Player to Dolly
 - Angle from Tangent of Rail at Dolly
 - Amount Boss obscures Player
 - Number of minor characters out of frame

Which means it's relatively easy to experiment with different cost functions.

For example, the distance from the dolly to the player, is fairly simple, and gives you the classic, drag or push the camera down the corridor, shot..

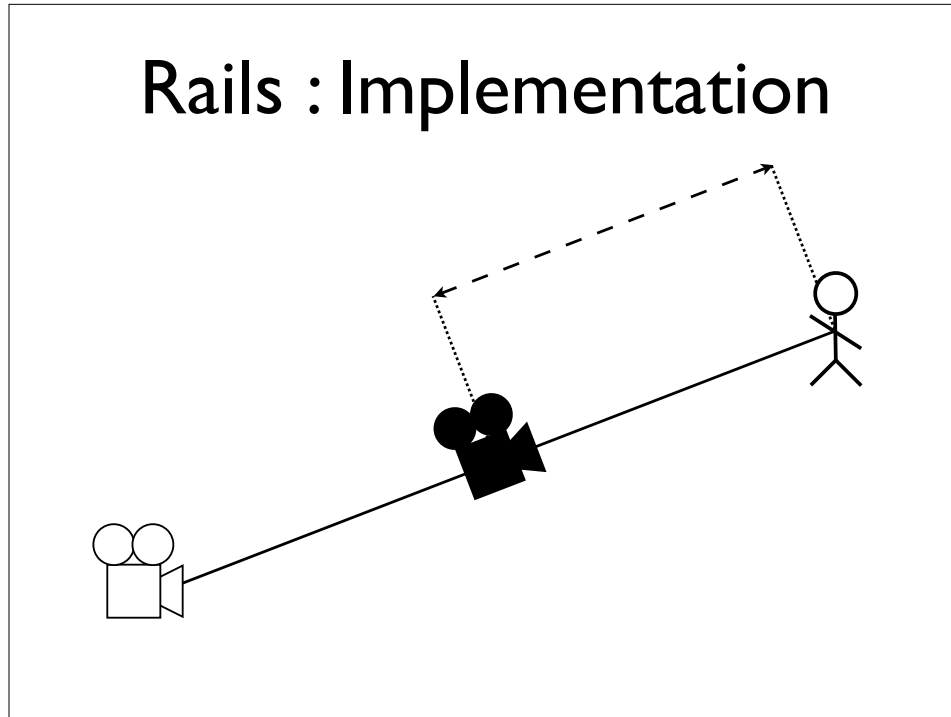
But the angle from the tangent of the rail at the dolly, which is the cost we would use for the tracking shot in the example, is a bit more complex.

Much more interesting cinematic costs:

For certain special cases, like Bosses, we can use cost to deal with the boss obscuring the player.

Probably the most complex cost we use, is related to the **number of minor characters that are out of frame**, and the amount they're out by.

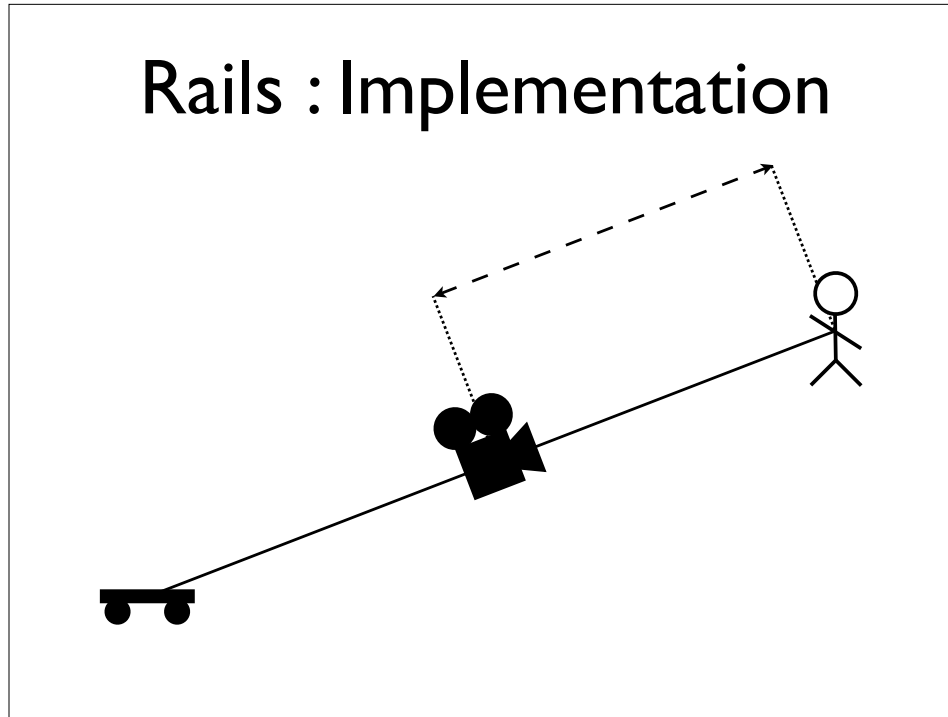
Rails : Implementation



So, having calculated the position of our dolly, we **combine** it with the camera dynamics we described earlier. Only instead of calculating distance and angle from the position and orientation of the camera node [in Maya], we derive them from the position and orientation of the **dolly** (where we consider the tangent of the rail at the dolly, to be the direction the dolly is pointing).

In fact you can consider the camera node, to be a dolly on a zero length rail.

Rails : Implementation



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Overview

- Zoning
- Dynamics
- Blending
- **Rails**

SUMMARY: In professional quality (AAA) camera control, there is a lot more involved than simple following cameras!

Other Stuff

- Dealing with multiple targets
- Target definition, and calculation
- Dealing with static and animated cameras
- Overriding cameras at arbitrary points to focus on dynamic areas of interest
- Framing fights, using multiple targets
- Damping
- Fragility of rotational blends
- Physical post effects like shake and sway

Not going to talk about.

End by looking again at God of War clip and trying to see where various techniques we talked about are used.