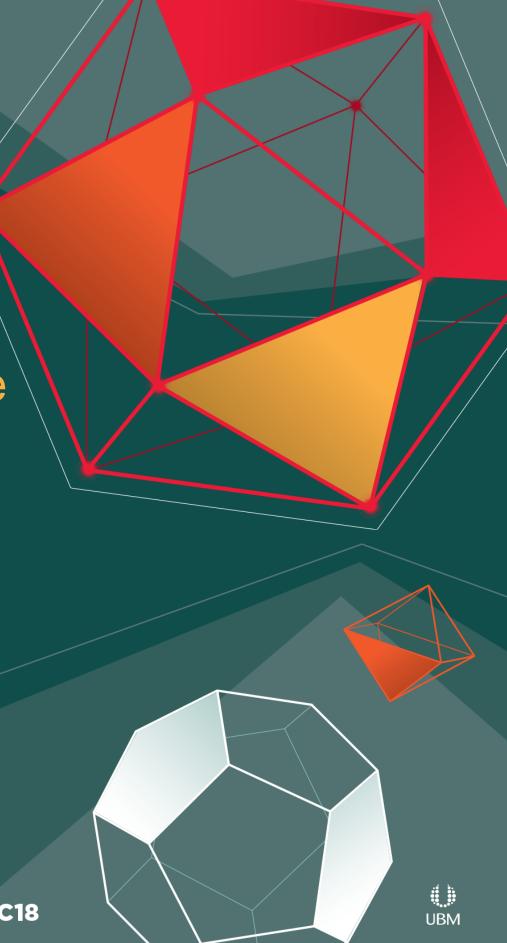
GDC®



8 Frames in 16ms

Rollback Networking in Mortal Kombat and Injustice

Michael Stallone Lead Software Engineer – Engine NetherRealm Studios mstallone@netherrealm.com



What is this talk about?

The how, why, and lessons learned from switching our network model from lockstep to rollback in a patch.





GDC GAME DEVELOPERS CONFERENCE® MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18

Staffing

- 4-12 concurrent engineers for 9 months
- Roughly 7-8 man years for the initial release
- Ongoing support is part time work for ~6 engineers





Terminology

- RTT Round trip time. Time a packet takes to travel from Client A > Client B > Client A
- Network Latency One way packet travel time
- Netpause Game pauses due to not receiving data from remote client for too long
- **QOS** Quality of Service. Measurement of connection quality





Terminology

- Input Latency Injected delay between a button press and engine response
- Confirm frame Most recent frame with input from all players
- Desync Clients disagree about game state, leads to a disconnect
- Dead Reckoning Networking model. Uses projections instead of resimulation





Basics

- Hard 60hz 1v1 fighting game
- Peer to Peer
- A network packet is sent once per frame
- Standard networking tricks to hide packet loss



frame packet loss



Determinism

The vast majority of our game loop is bit-for-bit deterministic.

We "fencepost" many values at various points in the tick, and any divergence causes a desync.

This is the foundation that everything is built on.





The Problem

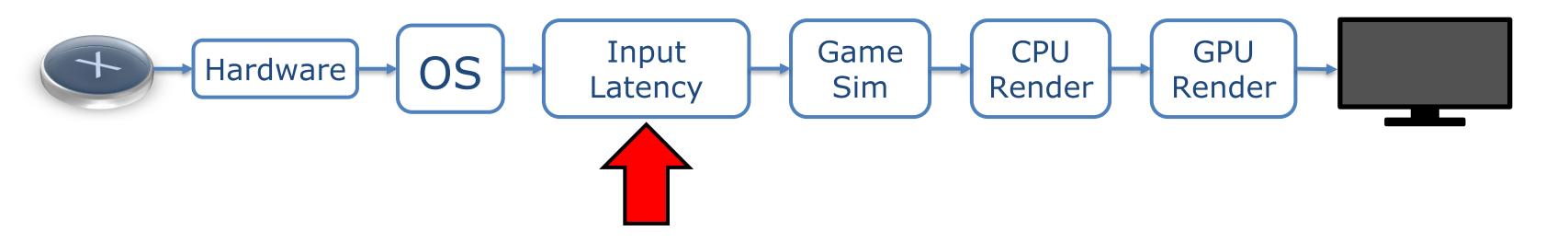
Our online gameplay suffered from inconsistent (and high) input latency.

The players were not happy.





Latency Diagram







GDC 2018 | EXPO: MARCH 21-23, 2018 #GDC18

Lockstep

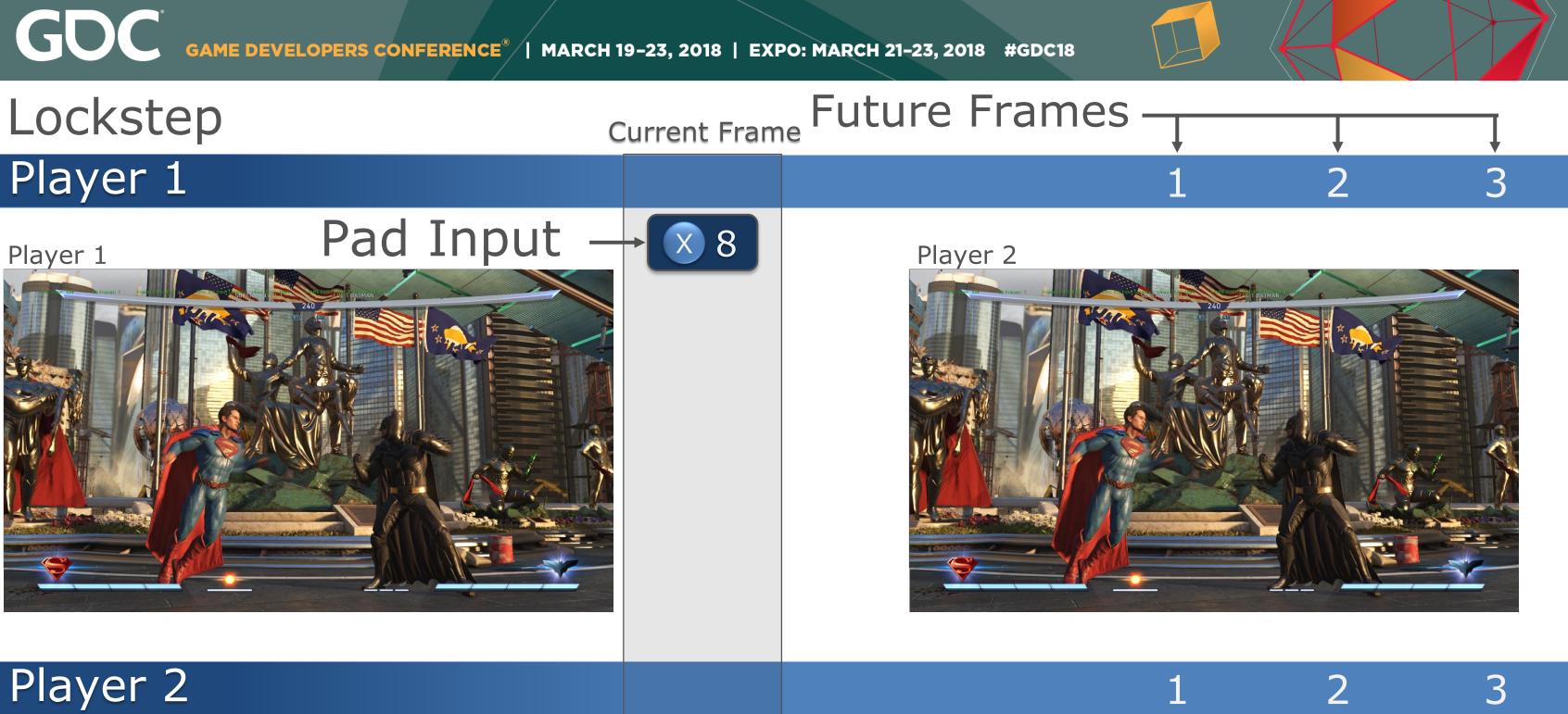
Only send gamepad data

The game will not proceed until it has input from the remote player for the current frame

Input is delayed by enough frames to cover the network latency









The Present

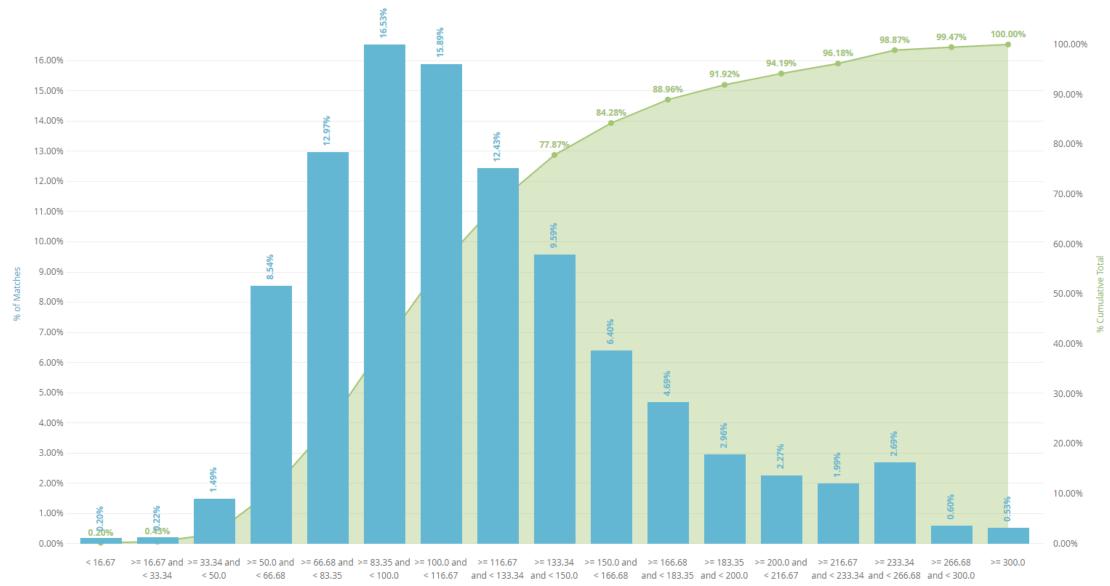
Mortal Kombat X and Injustice 2 have 3 frames of input latency and support up to 10 frames (333ms) of network latency before pausing the game.

The online experience is much improved and the players are happy.





Latency Curve







GOC GAME DEVELOPERS CONFERENCE MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18

Rollback

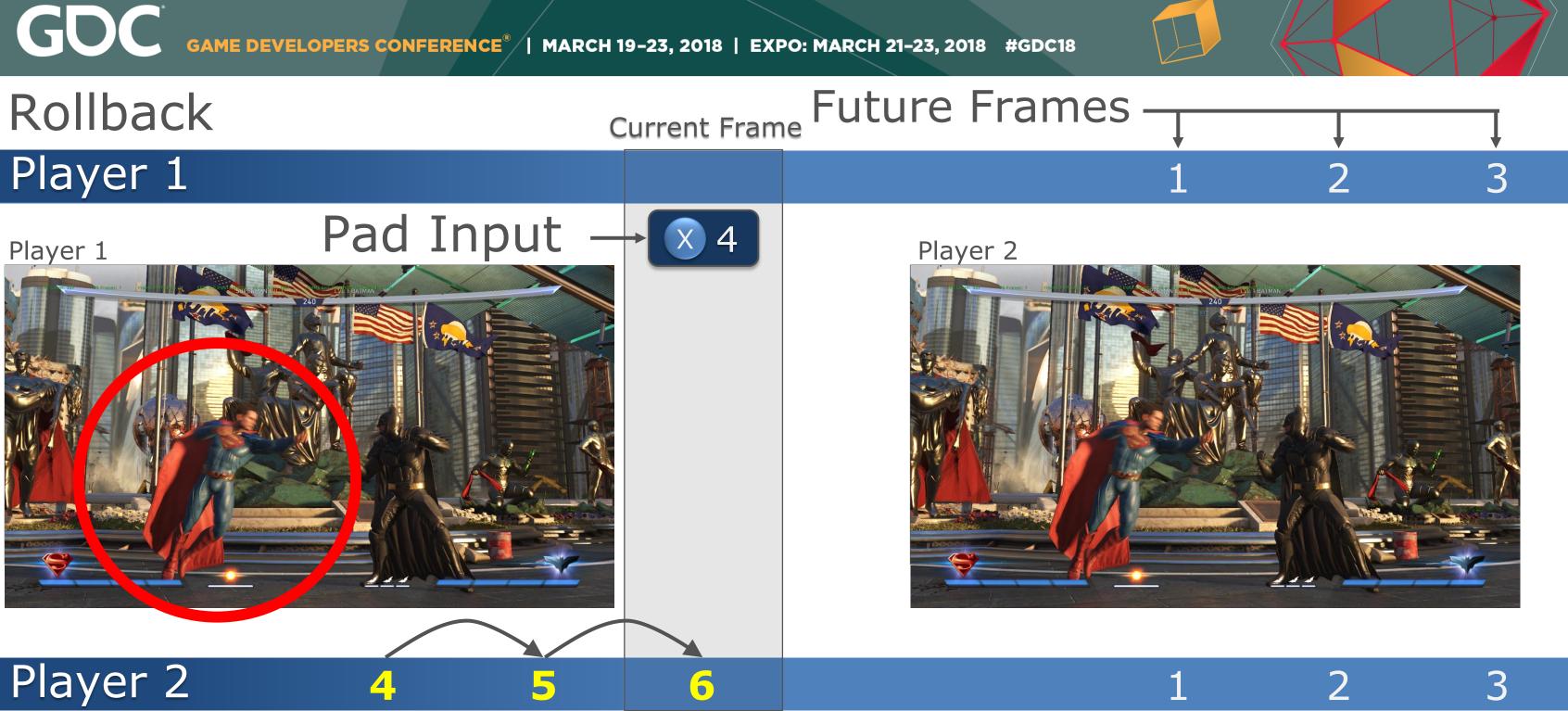
Only send gamepad data

Game proceeds without remote input

When remote input is received, rollback and simulate forward



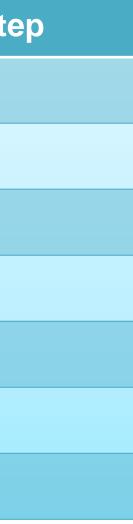






	Rollback	Lockst
Simple		X
Visually Smooth		X
Performant		X
Robust	X	X
Low Bandwidth	X	X
Responsive	X	
Single Frame Latency	X	







GDC GAME DEVELOPERS CONFERENCE MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18

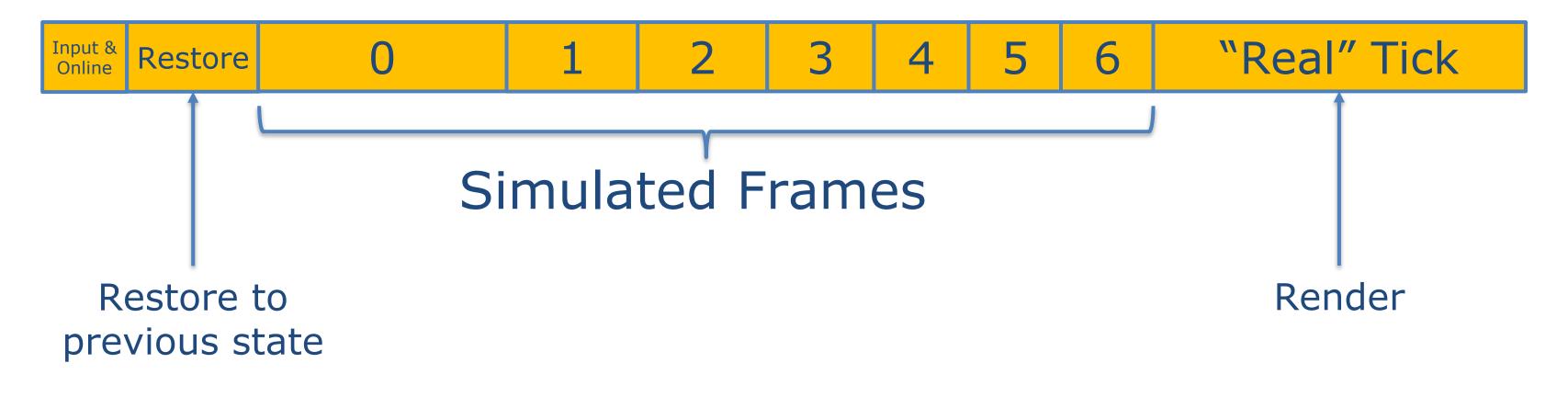
What did we do first?

- First goal was to get an idle character rolling back
- Turn off almost everything
- Serialization (Saving/Restoring previous state)
- Debug mode that constantly rolled back (SetRollbackFrames 7)





Tick Timeline (when rolling back)









GDC GAME DEVELOPERS CONFERENCE MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18

Serialization: Save

Rollback framework:

- Ring buffer (sized to rollback window)
- Object serialization interface
- Contains entries for object creation/destruction
- Only save mutable data
- Not delta based

virtual void DestroyFromStateTracker(UBOOL isUncreate); virtual void StateTrackerReactivate(); virtual void StateTrackerSuspend(); virtual SerializationPriority GetSerializationPriority() const; virtual void PostRestore(); virtual void SerializeData(Archive& Ar);





GDC GAME DEVELOPERS CONFERENCE -23. 2018 | EXPO: MARCH 21-23, 2018 #GDC18 MARCH 19

Serialization: Restore

- Parallel serialization
 - Cannot use shared_ptr
 - Simple load balancing and priority scheme
 - Large perf win (2.7 ms > 1.3 ms for double the work)
 - Waking threads is a bit slow
- Single threaded post-serialization fixup
 - Can coordinate with non-rollback systems
- Bulk-serialization and immutable data are hugely preferred





MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18

Object lifetime

Deferred Deletion

GDC

- Objects remain alive until their time of death is outside the rollback window
- Generally easier
- Code in destructors is dangerous
- Use handles
- Usually more performant

Delete and Recreate

- Delete objects as normal and create them again if needed
- This is the default
- Slow (unless reusing objects)
- Increased serialization
- Follows "normal" construction and destruction patterns





Recreatables

- Avoid creating the same object using "Re-Creatables"
- Used per type hashing to detect when an object was "identical"
- Sounds & particles were recreatable
 - Can be nondeterministic
 - Nondeterministic simulation means object reuse was mandatory
- Avoids wasteful creation
- Visual/Audio "correctness" without full serialization burden





What about gameplay script?

- Fiber based proprietary gameplay script
 - Fiber stack unwinding
 - Fiber stack serialization
 - Objects on the stack that require destructors can be a problem
 - We registered these objects with another system for cleanup



can be a problem ystem for cleanup



Rollback Artifacts

- When rollbacks occur, there can be a visual pop
- The extent of divergence varies wildly
 - Mostly minor
- Avoid rolling back large visual changes











How was performance?

- Bad. Real bad.
- Before rollbacks, we idled at 9-10ms on the CPU
- After initial rollback support, we idled at 30+ms
- Headroom due to console generation jump ... GONE!
- Tons of free cores

S Execution Timeline (Total Job Graph Time: 5.80304ms)												
	07ms	0.5ms	1ms	1.5ms	2ms	2.5ms	3ms	3.5ms	4ms	4.5ms	5ms	5.5ms
Thread 0x880F4C540												
Thread 0x880F50440												
Thread 0x880F508C0	RunGraphSyster	nJob (1.31299ms)	SMC	omp_SampleAnin	nat		UpdateHead	dTrackin SSI	nulate (0.3 TestFo	rOverlap (0.91023	Sms) St 🖌	Upc
Thread 0x880F50D40	Execut		E E U A SI	MComp_s	Mo				Up		/ Upc F	Par Par
Thread 0x880F511C0				F UI UF			UpdateHea	dTrackinc S SM	IComp_UpdateMւ	ıscl 🛛 🕴 Sim 1 Si	imi Te S SI SI	
Thread 0x880F51640	, A .		S S		: GameplayPo	stMotio SM(SN	٤ ٨٢		5 : : : SI 7			
Thread 0x880F51AC0			l Up	Ս Սբ								
Thread 0x880F51F40		, I	S	U Mor U	F					Carr Simul 1	Si	
Thread 0x880F523C0												



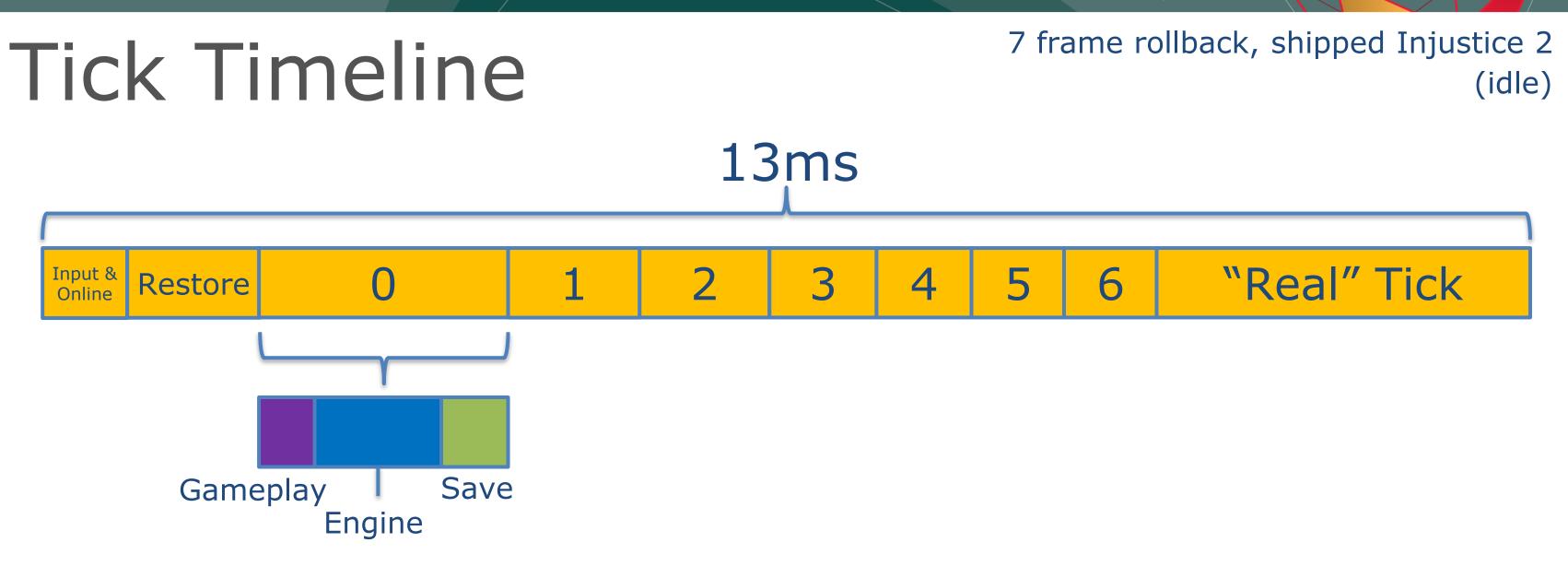


Performance Tools

- Sony/Microsoft perf tools
- Job Graph visualizer (task graph)
- Rollback loop (SUPER PAUSE!)
- PET Profiler
- Performance bots

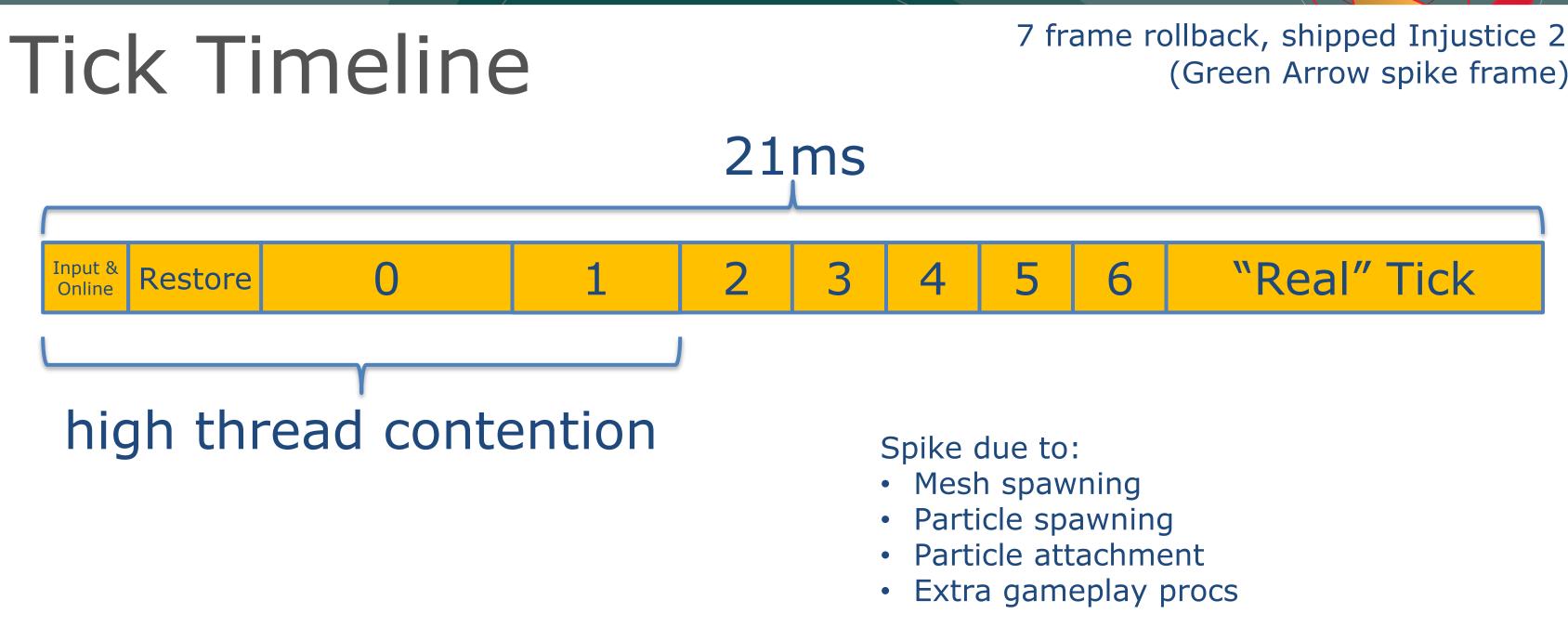








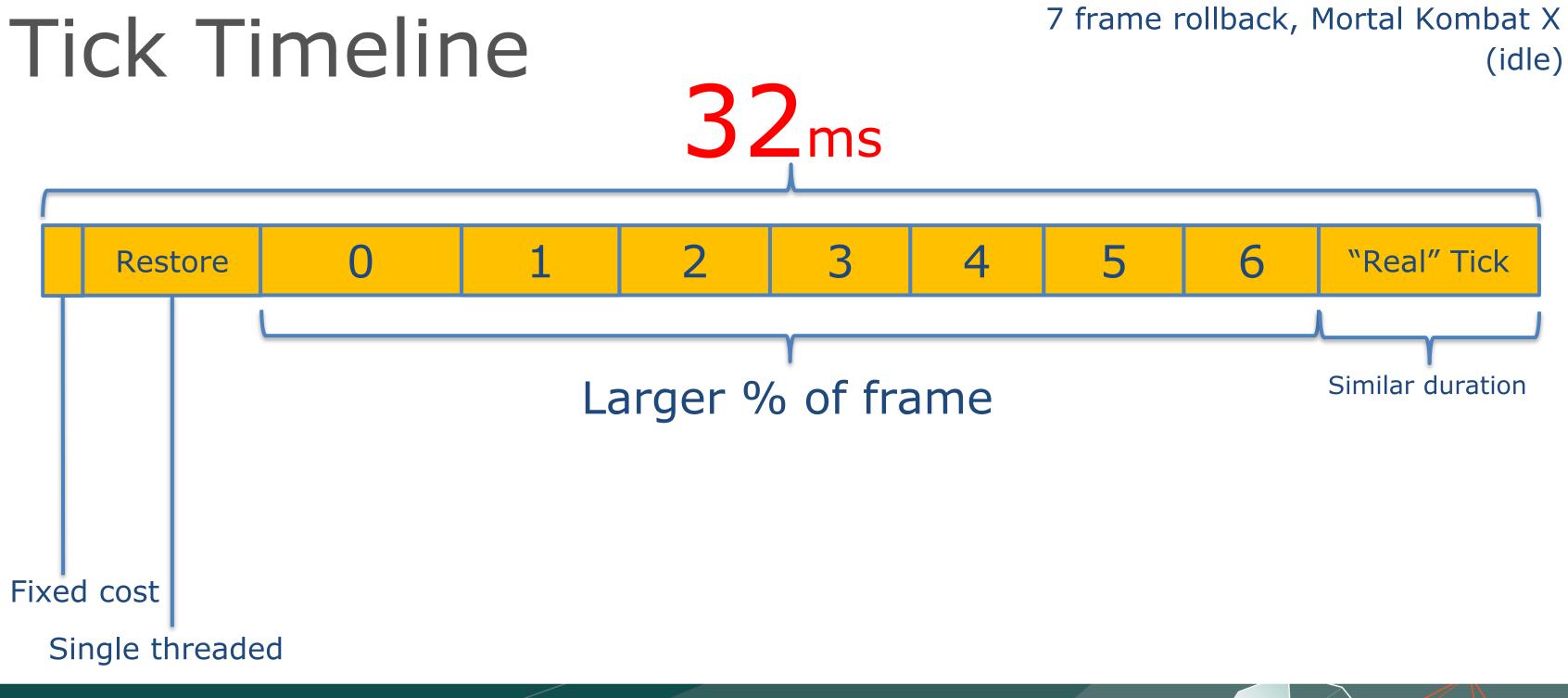
GDC GAME DEVELOPERS CONFERENCE MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18



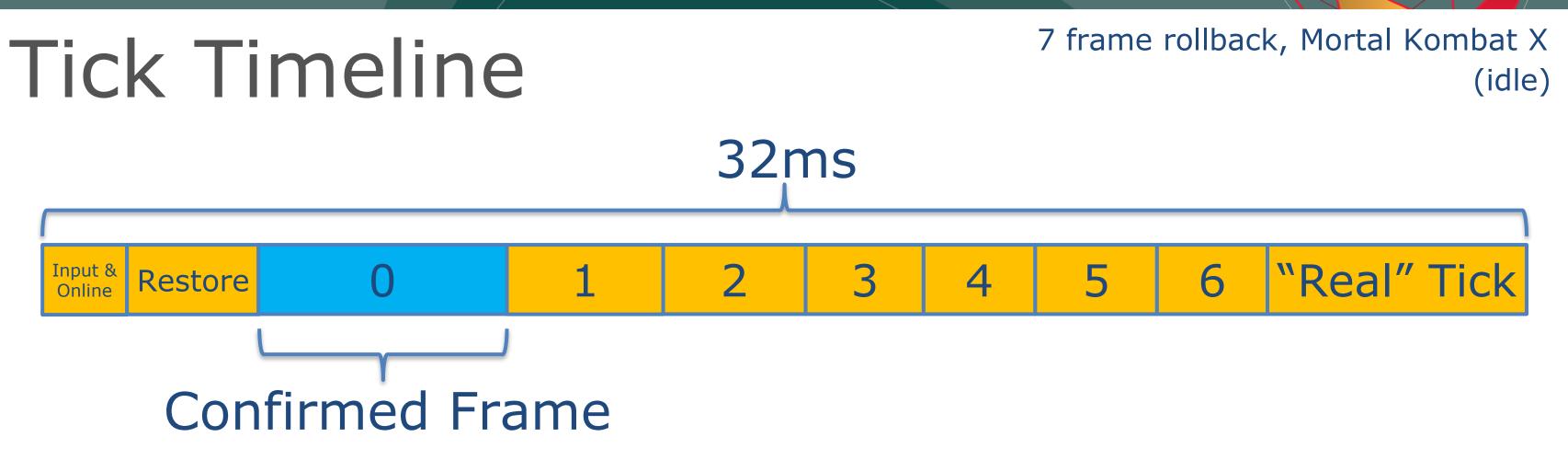
Spike can persist for 8 frames!



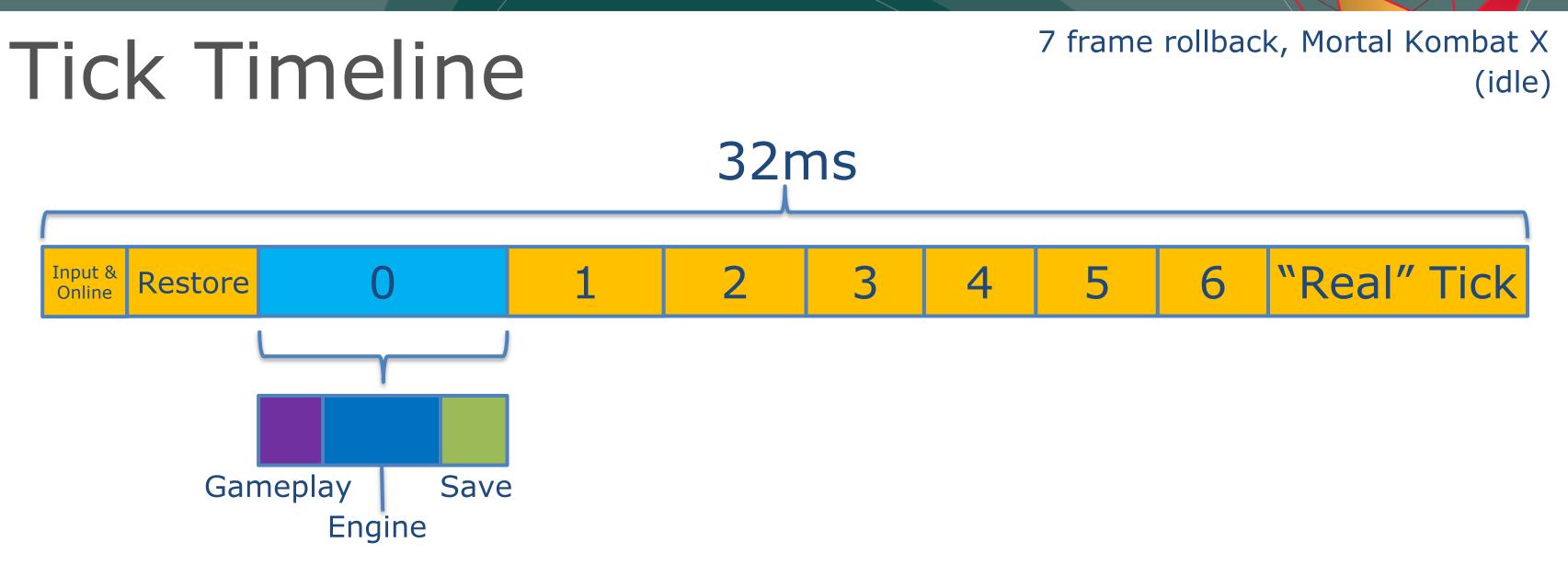
(Green Arrow spike frame)



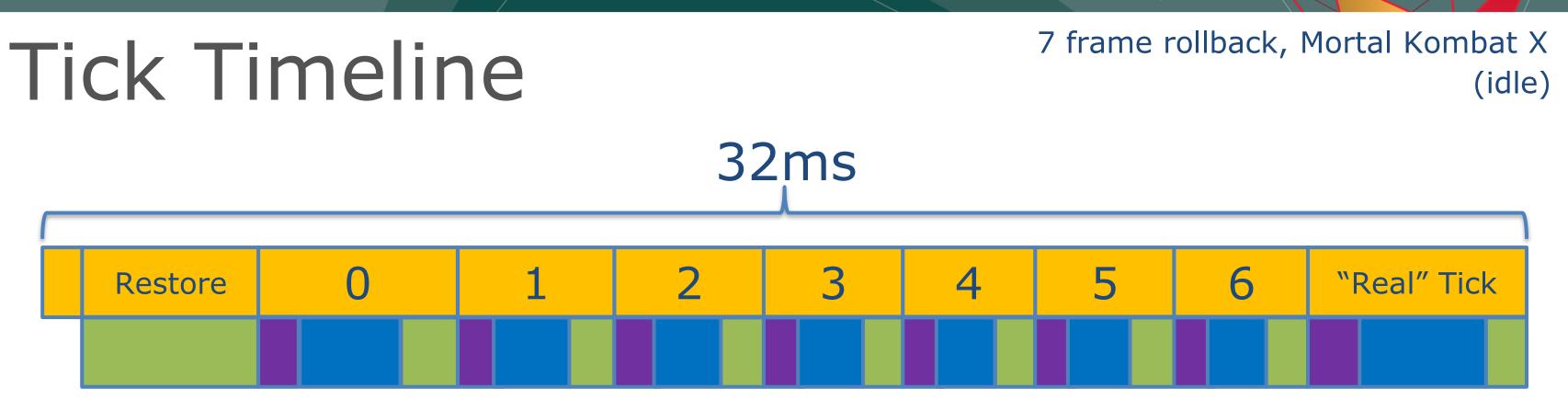












Gameplay Engine Save/Restore

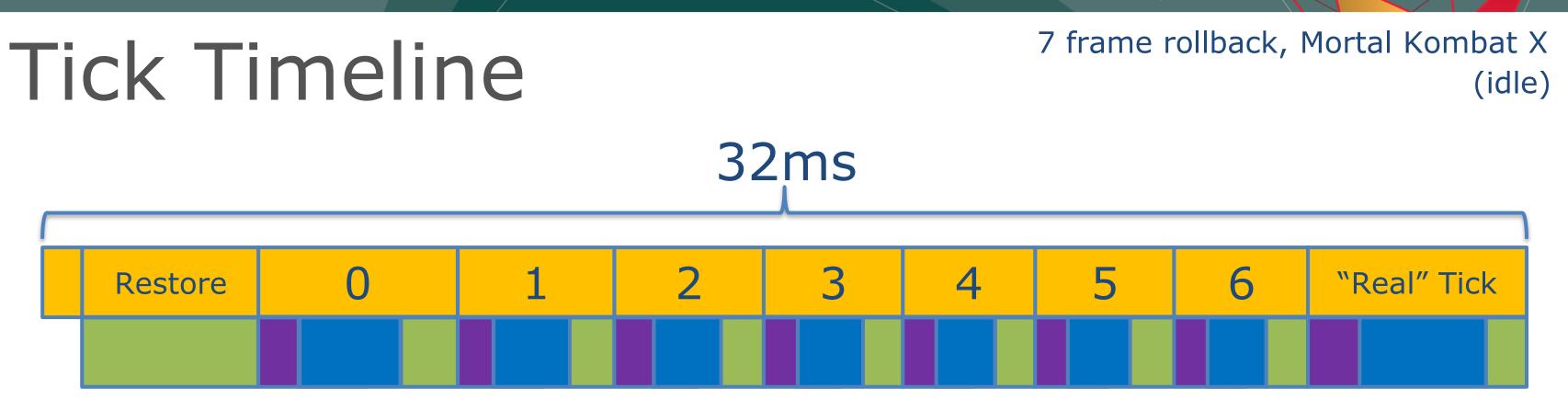


Turn off everything cool

- Physics/Cloth
- Raycasts that don't effect gameplay
- IK
- Particle effects
- Online
- Desync detection







Gameplay Engine Save/Restore



GOC GAME DEVELOPERS CONFERENCE® MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18

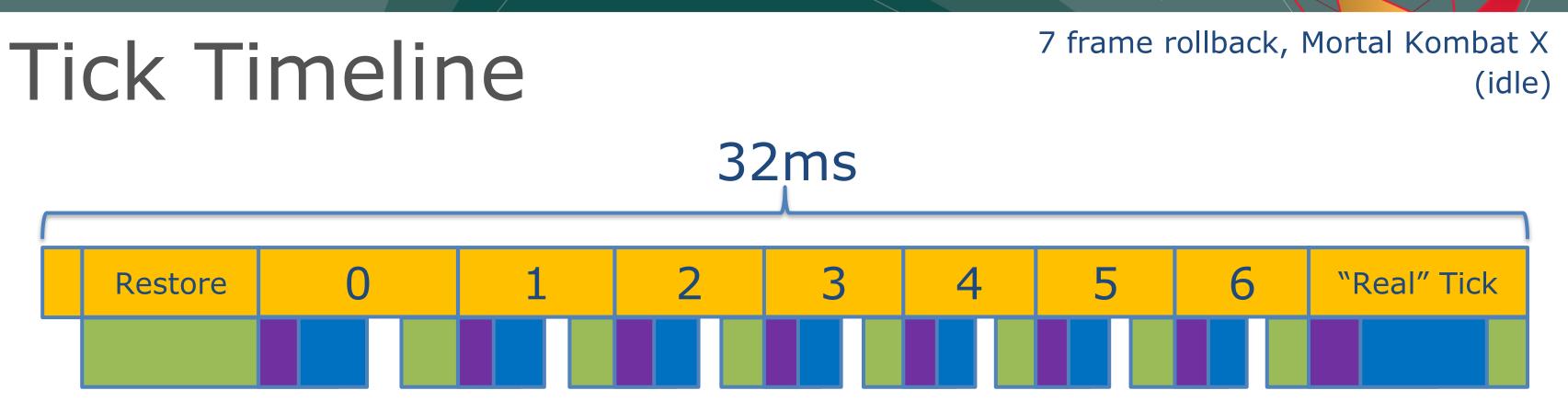
Easy performance wins

- Why are we strcmping?
- Don't do that 8 times
 - Controller polling
 - Garbage collection
- Opt out of system/object updates during simulation
- Death by a thousand cuts
 - Dynamic memory allocs
 - Pointer chasing
 - Walking sparse lists





GDC[®] GAME DEVELOPERS CONFERENCE[®] | MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18



GameplayEngineSave/Restore



GAME DEVELOPERS CONFERENCE MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18

More difficult performance wins

- Promotable re-simulation behavior
- Aggressive parallelization
- Graph optimizations

GOC

- Asynchronous UI/Audio ticking
- Automatic emitter parallelization
- Animation pre-sampling
- Simplify common graphs

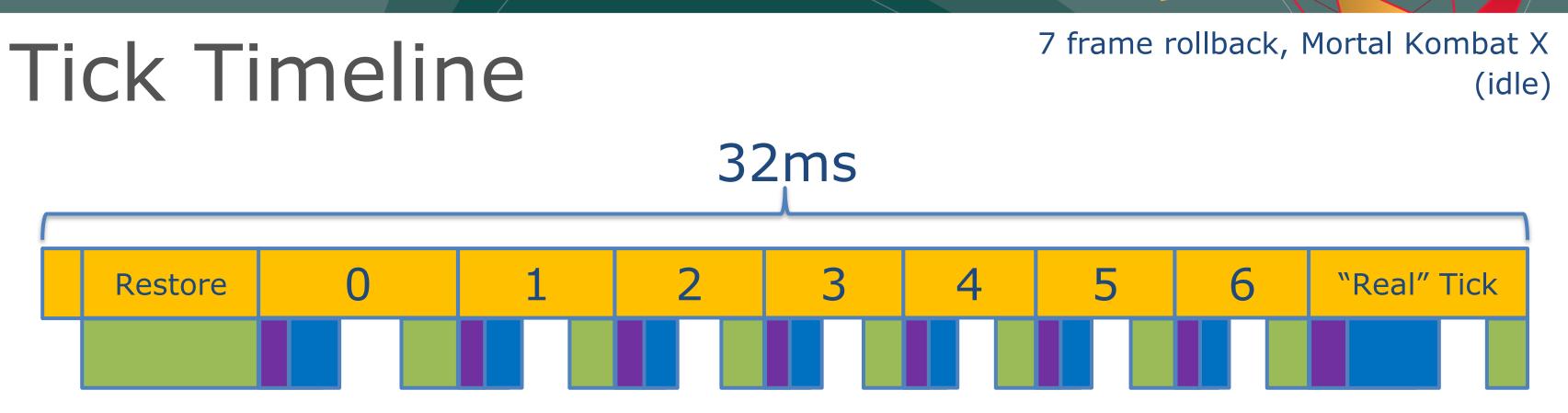
- Change graph types JIT
- More job priority levels



• Special case complex cases • Remove false dependencies



GDC[®] GAME DEVELOPERS CONFERENCE[®] | MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18



GameplayEngineSave/Restore



GDC GAME DEVELOPERS CONFERENCE[®] | MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18

You're only as fast as the critical path

Early Graph

	<mark>07ms</mark>	0.5ms	1ms	1.5ms	2ms	2.5ms	3ms	3.5ms	4ms	4.5ms
Thread 0x880F4C540										
Thread 0x880F50440										
Thread 0x880F508C0	RunGraphSyste	mJob (1.31299ms)	SMC	Comp_SampleAnim	nat		UpdateHea	dTrackinį S Sir	nulate (0.3 TestFo	rOverlap
Thread 0x880F50D40	Execut		E E U / / S	MComp_s	Mo				Up	
Thread 0x880F511C0		A A A		f Ul Up			UpdateHea	adTrackin <u>c</u> S SM	IComp_UpdateMւ	uscl K S
Thread 0x880F51640	. A .	4 4 4 1	S S	5	GameplayPo	ostMotio SM(S	M(5	5 5	5 : : : SI 4	
Thread 0x880F51AC0			l Up	Ul Uk						
Thread 0x880F51F40		, E	S	U Mor U	F					Carr
Thread 0x880F523C0										
						Y				



	Oms	0.25ms	0.5ms	0.75ms	1ms	1.25ms	1.5ms	1.75ms	2ms	2.25ms 2.465	9 <mark>ms</mark> .5ms	2.75ms
nread 0x17C												
nread 0x184	ΑΑ(Λ SN	/ MorphCon 🕴	A 12 .	5 A 5 1	1 1 1 I I I I I I I I I I I I I I I I I	A A SMC	Simulate / S 💠	I <u>5</u>	, SN PC / SN	Aci Upo	lateFrameData (0.441	68ms)
nread 0x188	I WorldKickSubg	graphs (0.81662ms	5)	L 5 U	p SI I Update	ProxyTicl P(+ :	Simulat S	. LISN SIS	: : S	S : SMCom	p_Sam_Morph : SI :	
nread 0x18C	A SMC	on AAAACA	Up / Ac / S I	A []]L A [] S	I SN Cam	ر د ۲	SimulateN	UpdateF	Proxy A 1 A	55,1.	Լ Սpւ	Uj
nread 0x190	SMCom	p_IA/SI/.P	.	Gamepl S	: S	SN 5 SM	ICon 🗄 SM	Up I SMC	S SN 5	. UpdatePrc F	М	Mot
nread 0x194	Ac / SM	IC MorphCon	S 1 5 A . 1	I U /	I Exe	Exe E 4 5 K	Simulate I SM	U / 5	5 SN 5	I I	Up	SMC
nread 0x198	Ac . /	1 A A A .	F.F.F.F	SSI Execute	eHavo ! S	A Exect	SimulateN S	l I I S I	SS / A			

~3ms for a LOT more work!

Shipping Graph

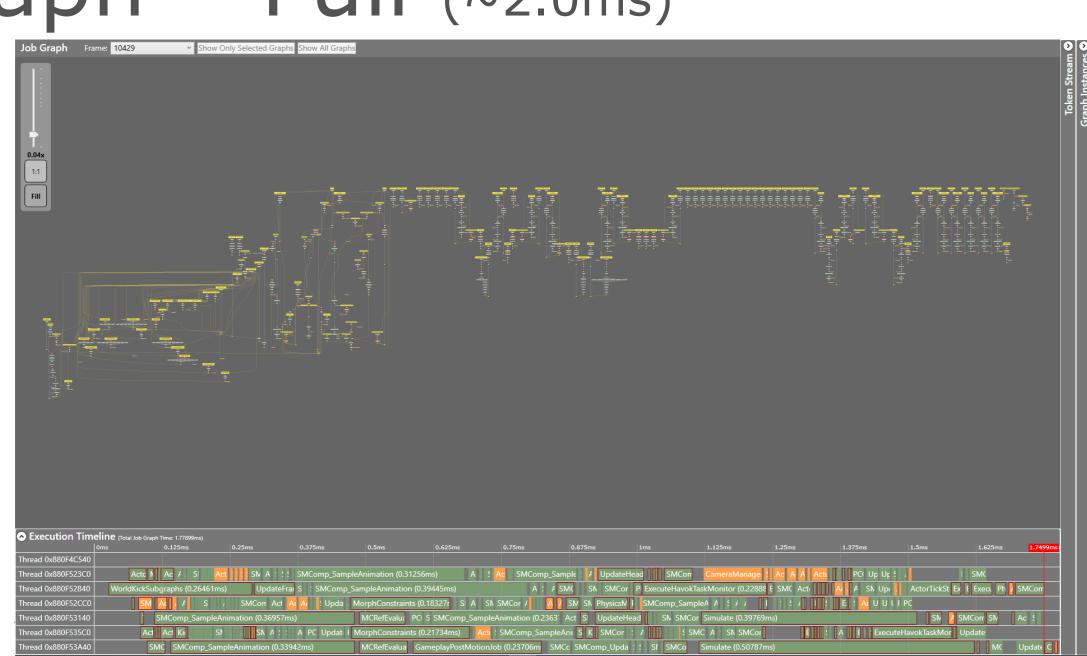


	5ms			5.5m	5
ар (0.91023	ms)	St /		Upc	
		ιU	pc Pa	ar	Par
k Sim 1 Si	m Te S	SI S	SI		
		[
an Simul 1	Si				



GDC[®] GAME DEVELOPERS CONFERENCE[®] | MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18

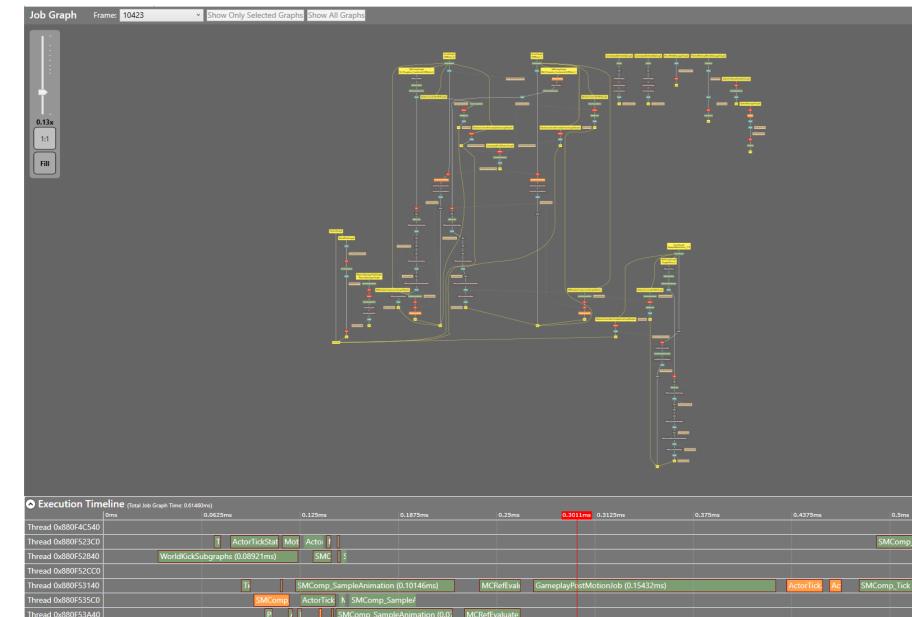
Job Graph – Full (~2.0ms)



UBM

GDC[°] GAME DEVELOPERS CONFERENCE[°] | MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18

Job Graph – Sim (~0.5ms)



Token Stream	Graph Instances 🗸
2	Gra
0.5625ms Tick (0.0 MCRefEva ActorTick S	

UBM

GAME DEVELOPERS CONFERENCE MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18

So... about that threading

• Thread contention is real

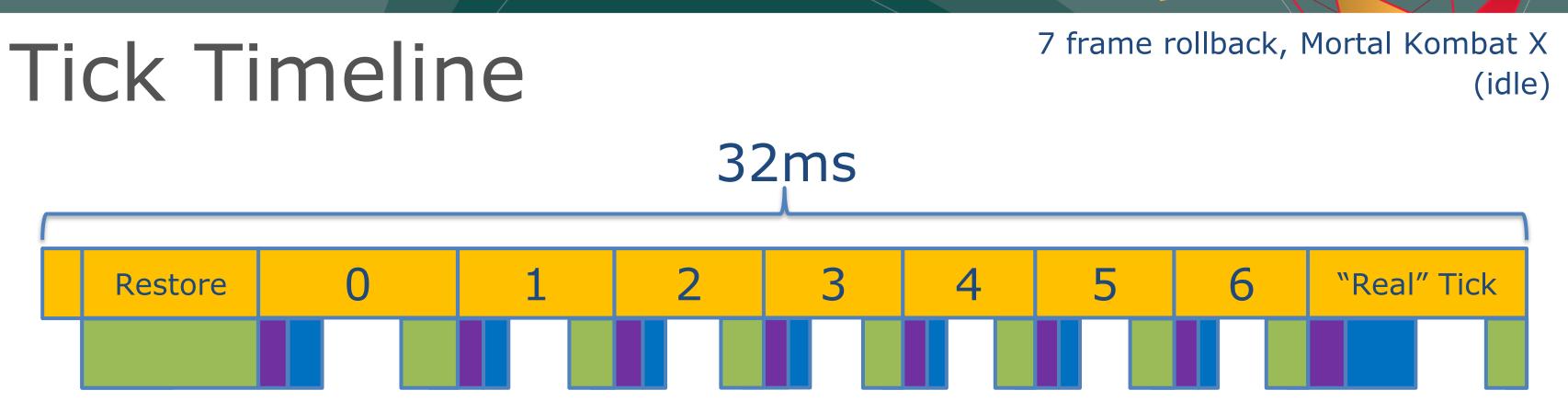
GOC

- Manage thread priorities and affinities
- Don't over-subscribe threads
- Drop thread priority for low priority or latency tolerant work
- Careful of priority inversion and starvation!
- Threading primitives can cost more than they are worth
 - Useful migration pattern
 - Use Move semantics to avoid unnecessary atomic operations
 - E.g. Handle copying





GDC[®] GAME DEVELOPERS CONFERENCE[®] | MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18



GameplayEngineSave/Restore



GDC GAME DEVELOPERS CONFERENCE[®] | MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18

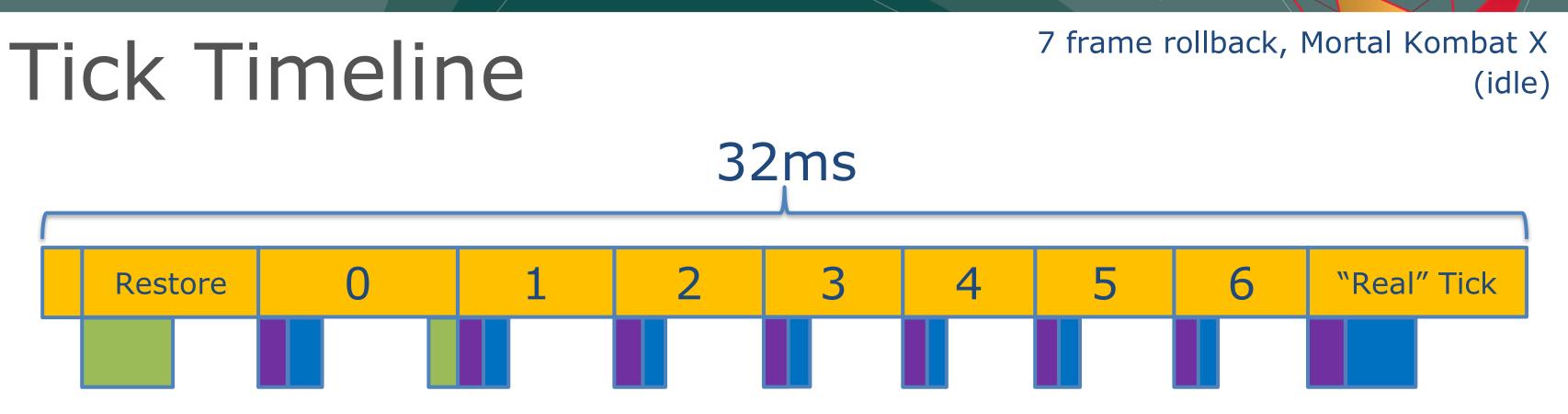
Do you have to save 8 times?

- **KEY INSIGHT!** You only need to save the confirmed frame!
 - Large optimization for the worst case
 - Makes average case slower (rollback further)





GDC GAME DEVELOPERS CONFERENCE[®] | MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18

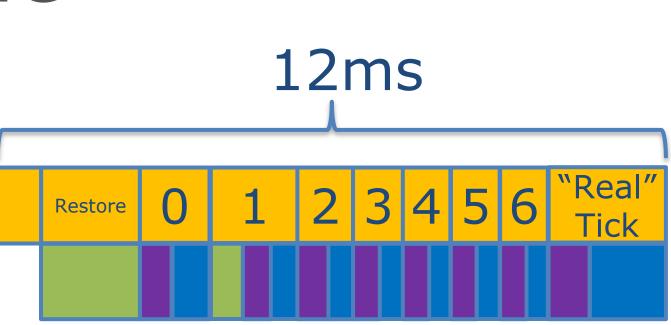






GDC[®] GAME DEVELOPERS CONFERENCE[®] | MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18

Tick Timeline





7 frame rollback, Mortal Kombat X (idle)



GDC GAME DEVELOPERS CONFERENCE MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18

Particle Performance

- Particles were special
 - Naïve approaches WAY too expensive
- Particle systems were the largest cause of performance spikes
- Heavy caching
- Deferred async initialization of particle systems
- Automatic emitter parallelization





GDC GAME DEVELOPERS CONFERENCE[®] | MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18

Particle Resim Modes

- **RESIM_ALWAYS** N simulations, 1 serialization
 - Simulate this particle every frame
- **RESIM_NEVER** 1 simulation, 1 serialization
 - Simulate on the render frame
- **RESIM_PREDICTIVE** 2 simulations, 1 serialization
 - <u>Simulate on the confirm and the render frame</u>
- **RESIM_NOT_TRACKED** 1 simulation, 0 serializations
 - Simulate on the render frame





GDC GAME DEVELOPERS CONFERENCE MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18

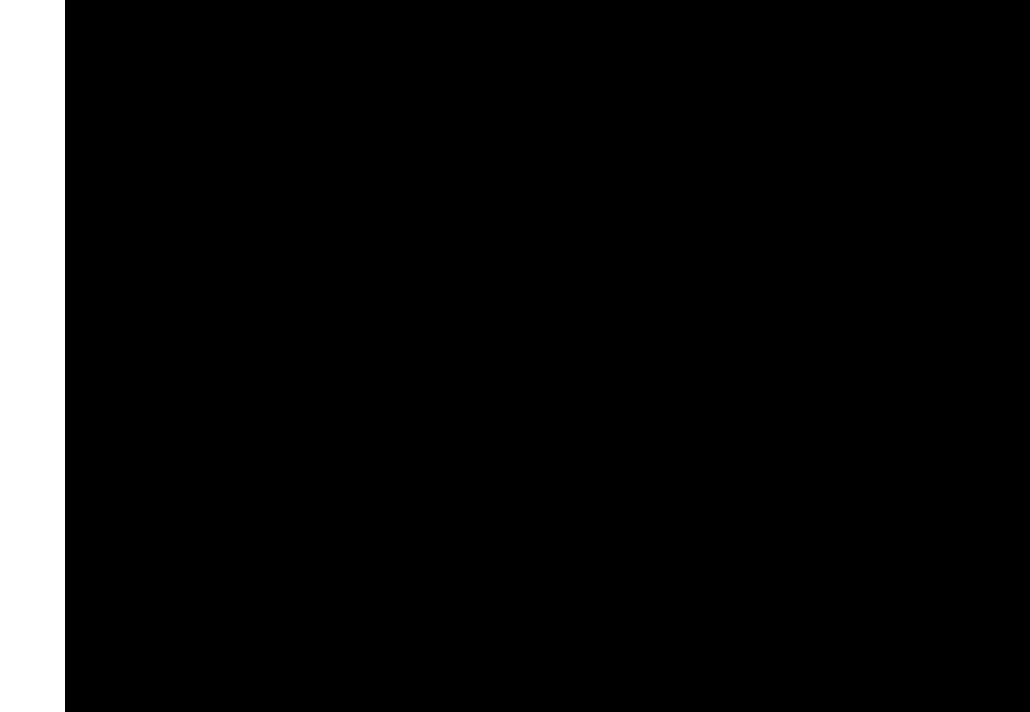
Predictive Particle Cache

- Predictive ticking/serialization
 - May cause visual discontinuities
 - Visual defects mitigated with custom particle state cache
 - Hashed each frame (not just on creation)
 - If particle simulation inputs match cache entry, use cache
- This was EXTREMELY effective
- This is a good template for areas that do not have to be perfect











() UBM GDC GAME DEVELOPERS CONFERENCE® MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18

Checking our work

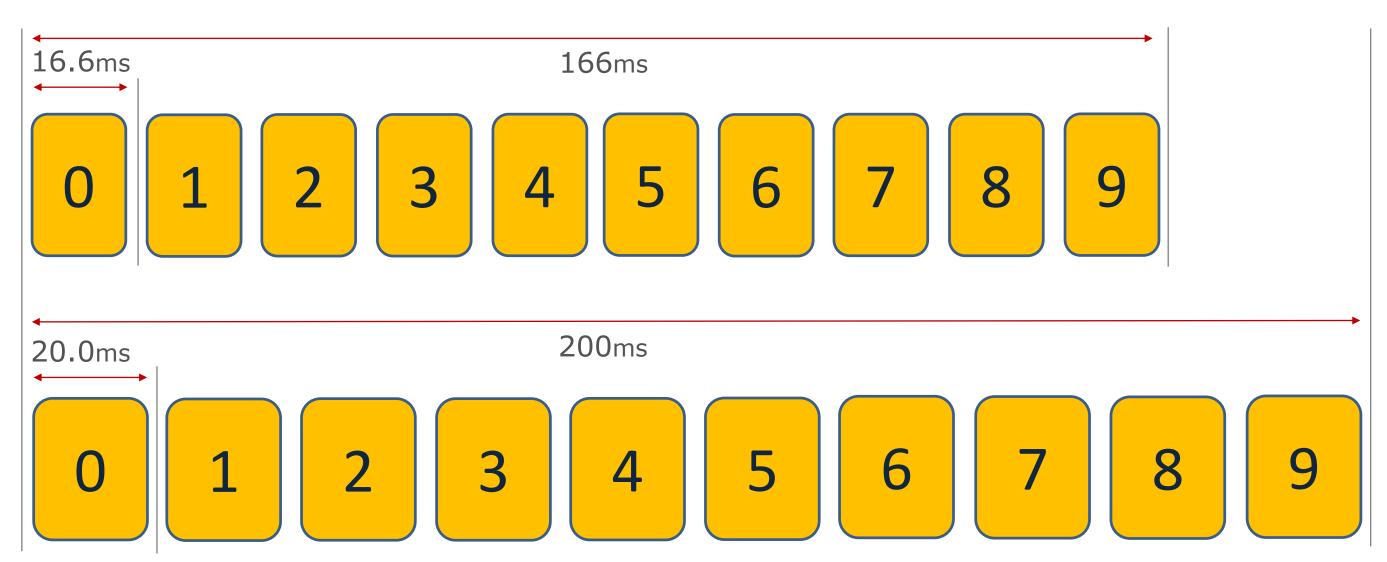
- QA told us the game was playing GREAT
 - Had been focused on SetRollbackFrames 7
- We were still bogging and net-pausing in our worst cases
 - The net-pauses felt MUCH worse than bogging
- Enter Frame Lengthening!





GDC^{*} GAME DEVELOPERS CONFERENCE[®] | MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18

Frame Lengthening







Beta

- Run a beta!
 - ~20,000 users
- Very positive public response
 - 95% of the players rated it as "as good or better"
- Solidified our performance and network targets







Curveball

- First beta telemetry demonstrated unexpected results
 - Most matches ended up constantly rolling back the maximum
 - Caused by one player getting ahead of the other player
 - Effectively a performance feedback loop
 - Players loved it anyway!
 - Solved by artificially slowing down the player who was ahead
 - Re-used the Frame Lengthening tech





Fine Tuning

- Analyzed our rollback counts
- Used "speculative saves" to reduce rollbacks
- You don't have to save more than once, but maybe you should...





GDC GAME DEVELOPERS CONFERENCE MARCH 19-23, 2018 | EXPO: MARCH 21-23, 2018 #GDC18

Speculative saves (spec saves)

- Save the confirmed frame (mandatory)
- Save after the simulation mid point (time permitting)
 - Bias this save closer to the confirmed frame
- Save at the end of the frame (time permitting)
- Thresholds are tweakable without patching
- Spec saves reduced total rollback count by 30%





What about all the desyncs?

- Not running procedural systems during simulation caused desyncs
- Luckily, our tools improved to compensate!
- Offline desync detection
- Remote input capture with network delays
 - Allows the match to be replayed
 - Allows breadcrumbs to be added after the fact
 - Invaluable
- Final desync rate less than 0.1%



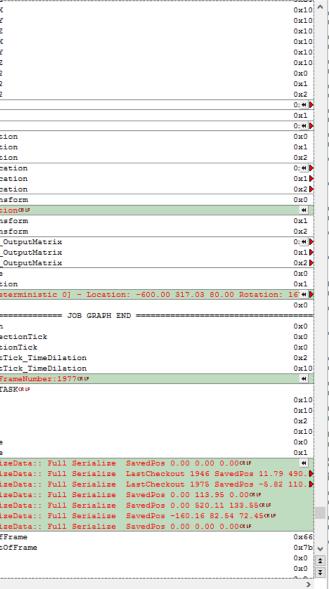




Desync Log

18037 0	1976	22						22	EVENT Collision Colnode X
									EVENT Collision Colnode Y
									EVENT Collision Colnode Z
									EVENT Collision Colnode X
									EVENT_Collision_Colnode_Y
									EVENT Collision Colnode Z
									[X] EVENT MCRM AnimLocation 2
									[X] EVENT_MCRM_ANIMLOCAtion_2 [X] EVENT MCRM AnimLocation 2
									[X] EVENT_MCRM_AnimLocation_2 [X] EVENT_MCRM_AnimLocation_2
					г				
					4				[X] EVENT_MCRM_MotionDelta
					r d				[X] EVENT_MCRM_MotionDelta
					4				[X] EVENT_MCRM_MotionDelta
				·	r				[X] EVENT_MCRM_UncommittedMotic
									[X] EVENT_MCRM_UncommittedMotic
					г				[X] EVENT_MCRM_UncommittedMotic
					, II				[X] EVENT_MCRM_TransformedLocat
									[X] EVENT_MCRM_TransformedLocat
					r 4				[X] EVENT_MCRM_TransformedLocat
] _				[X] EVENT_MCRM_WorldSpaceTransf
				0.~0					
									[X] EVENT_MCRM_WorldSpaceTransf
					, _				[X] EVENT_MCRM_WorldSpaceTransf
									[X] EVENT_MCAT_PostConstrain_Out
18060 0			[X] EVENT_MCAT_PostConstrain_OutputMatrix					2	[X] EVENT_MCAT_PostConstrain_Ou
18061 0			[X] EVENT_MCAT_PostConstrain_OutputMatrix		JL			2	<pre>[X] EVENT_MCAT_PostConstrain_Ou</pre>
18062 0			[X] EVENT_Time_ActorDeltaTime			18072	0 1976	2	[X] EVENT_Time_ActorDeltaTime
			[X] EVENT_Time_ActorTimeDilation	0.~1				2	[X] EVENT_Time_ActorTimeDilation
18064 0	1976	2	EVENT_JobGraph_End	0.00	[18074	[LOG - 1976]	InternalGet	IdealLocationRotationFromPoints[Dete
								2	EVENT_JobGraph_End
18066 0			EVENT_DesyncHash_JobGraph						
18067 0	1976	22	EVENT_Collision_BeginDetectionTick	0x0		18077	0 1976	2	EVENT_DesyncHash_JobGraph
18068 0	1976	22	EVENT_Collision_EndDetectionTick	0x0		18078	0 1976	22	EVENT_Collision_BeginDetect
18069 0	1976	24	EVENT_FGCharacterObj_PostTick_TimeDilation	0x2		18079	0 1976	22	EVENT_Collision_EndDetection
18070 0	1976	24	EVENT_FGCharacterObj_PostTick_TimeDilation	0.~10	_	18080	0 1976	24	EVENT_FGCharacterObj_PostTi
18071 [LOG - 1976] Sta	art async to	sk: HUD_COMBO_STRIKE_COOLDOWN_TASK@#			18081	0 1976	24	EVENT_FGCharacterObj_PostTi
18072 0	1976	24	EVENT_AsyncTask_StartA	0x10	\sim	18082	[LOG - 1976]	MKCameraMan	ager::UpdateCinemaCameraInfo() - Fra
18073 0	1976	24	EVENT_AsyncTask_StartB	0x10		18083	[LOG - 1976]	Start async	task: HUD_COMBO_STRIKE_COOLDOWN_TAS
18074 0	1976	23	[X] EVENT_CheckLifeBarUpdate	0x2		18084	0 1976	24	EVENT_AsyncTask_StartA
18075 0	1976	23	[X] EVENT_CheckLifeBarUpdate	0x10		18085	0 1976	24	EVENT_AsyncTask_StartB
18076 0	1976	23	[X] EVENT_CheckSuperBarUpdate	0x0		18086	0 1976	23	[X] EVENT_CheckLifeBarUpdate
10077 0		23	[X] EVENT_CheckSuperBarUpdate	0.21		18087	0 1976	23	[X] EVENT_CheckLifeBarUpdate
19011 0	1976					18088	0 1976	23	[X] EVENT_CheckSuperBarUpdate
18078 0		1	[X] EVENT_DesyncTracker_EndOfFrame	0x06	\backslash	18088			
	1976	1		0x06 0x7b		18088		23	[X] EVENT CheckSuperBarUpdate
18078 0	1976 1976		[X] EVENT_DesyncTracker_StartOfFrame			18089			[X] EVENT_CheckSuperBarUpdate FRAME: 1976 - DEBUG TEXT: Serialize
18078 0 18079 0	1976 1976 1976	1	[X] EVENT_DesyncTracker_StartOfFrame EVENT_Game_GameTick	0x7b		18089 18090	0 1976 [LOG - 1976]	CHANNEL: -	FRAME: 1976 - DEBUG_TEXT: Serialize
18078 0 18079 0 18080 0	1976 1976 1976 1976	1 19	[X] EVENT_DesyncTracker_StartOfFrame EVENT_Game_GameTick EVENT_Game_DeltaTime	0x7b 0x0		18089 18090	0 1976 [LOG - 1976]	CHANNEL: -	
18078 0 18079 0 18080 0 18081 0	1976 1976 1976 1976 1976	1 19 18	[X] EVENT_DesyncTracker_StartOfFrame EVENT_Game_GameTick EVENT_Game_DeltaTime EVENT_Player_Life	0x7b 0x0 0x0		18089 18090 18091 18092	0 1976 [LOG = 1976] [LOG = 1976] [LOG = 1976]	CHANNEL: - CHANNEL: -	FRAME: 1976 - DEBUG_TEXT: Serialize FRAME: 1976 - DEBUG_TEXT: Serialize
18078 0 18079 0 18080 0 18081 0 18082 0 18082 0	1976 1976 1976 1976 1976 1976	1 19 18 23 23	[X] EVENT_DesyncTracker_StartOfFrame EVENT_Game_GameTick EVENT_Game_DeltaTime EVENT_Player_Life EVENT_Player_Life	0x7b 0x0 0x0 0x2 0x10		18089 18090 18091 18092 18093	0 1976 [LOG - 1976] [LOG - 1976] [LOG - 1976] [LOG - 1976]	CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: -	FRAME: 1976 - DEBUG_TEXT: Serialize FRAME: 1976 - DEBUG_TEXT: Serialize FRAME: 1976 - DEBUG_TEXT: Serialize FRAME: 1976 - DEBUG_TEXT: Serialize
18078 0 18079 0 18080 0 18081 0 18082 0 18083 0 18083 0	1976 1976 1976 1976 1976 1976 1976	1 19 18 23 23 16	<pre>[X] EVENT_DesyncTracker_StartOfFrame EVENT_Game_GameTick EVENT_Game_DeltaTime EVENT_Player_Life EVENT_Player_Life EVENT_Input_Current_P1</pre>	0x7b 0x0 0x2 0x2 0x10 0x0		18089 18090 18091 18092 18093 18094	0 1976 [LOG - 1976] [LOG - 1976] [LOG - 1976] [LOG - 1976] [LOG - 1976]	CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: -	FRAME: 1976 - DEBUG_TEXT: Serialize FRAME: 1976 - DEBUG_TEXT: Serialize FRAME: 1976 - DEBUG_TEXT: Serialize FRAME: 1976 - DEBUG_TEXT: Serialize FRAME: 1976 - DEBUG_TEXT: Serialize
18078 0 18079 0 18080 0 18081 0 18082 0 18083 0 18083 0 18084 0 18085 0	1976 1976 1976 1976 1976 1976 1976 1976	1 19 18 23 23 16 16	<pre>[X] EVENT_DesyncTracker_StartOfFrame EVENT_Game_GameTick EVENT_Game_DeltaTime EVENT_Player_Life EVENT_Player_Life EVENT_Input_Current_P1 EVENT_Input_Current_P1 EVENT_Input_Prev_P1</pre>	0x7b 0x0 0x2 0x10 0x10 0x10 0x0		18089 18090 18091 18092 18093 18094 18095	0 1976 [LOG - 1976] [LOG - 1976] [LOG - 1976] [LOG - 1976] [LOG - 1976] [LOG - 1976]	CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: -	FRAME: 1976 - DEBUG_TEXT: Serialize FRAME: 1976 - DEBUG_TEXT: Serialize
18078 0 18079 0 18080 0 18081 0 18082 0 18083 0 18083 0 18085 0 18086 0	1976 1976 1976 1976 1976 1976 1976 1976	1 19 18 23 23 16 16 16	<pre>[X] EVENT_DesyncTracker_StartOfFrame EVENT_Game_GameTick EVENT_Game_DeltaTime EVENT_Player_Life EVENT_Player_Life EVENT_Input_Current_P1 EVENT_Input_Prev_P1 EVENT_Input_Current_P2</pre>	0x7b 0x0 0x2 0x10 0x0 0x0 0x0		18089 18090 18091 18092 18093 18094 18095 18096	0 1976 [LOG - 1976] 1976] [LOG - 1976] 1976] [LOG - 1976] 1976] [LOG - 1976] 1976]	CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: -	FRAME: 1976 - DEBUG_TEXT: Serialize FRAME: 1976 - DEBUG_TEXT: Serialize
18078 0 18079 0 18080 0 18081 0 18082 0 18083 0 18084 0 18085 0 18085 0 18086 0	1976 1976 1976 1976 1976 1976 1976 1976	1 19 23 23 16 16 16 16	<pre>[X] EVENT_DesyncTracker_StartOfFrame EVENT_Game_GameTick EVENT_Game_DeltaTime EVENT_Player_Life EVENT_Input_Life EVENT_Input_Current_P1 EVENT_Input_Prev_P1 EVENT_Input_Prev_P2 EVENT_Input_Prev_P2</pre>	0x7b 0x0 0x2 0x10 0x0 0x0 0x0 0x0 0x0		18089 18090 18091 18092 18093 18094 18095 18096 18097	0 1976 [LOG = 1976] 1976 0 1976	CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: -	<pre>FRAME: 1976 - DEBUG_TEXT: Serialize FRAME: 1976 - DEBUG_TEXT: Serialize (X) EVENT_DesyncTracker_EndOffer</pre>
18078 0 18079 0 18080 0 18081 0 18082 0 18083 0 18084 0 18085 0 18086 0 18086 0 18088 0	1976 1976 1976 1976 1976 1976 1976 1976	1 19 18 23 23 16 16 16 16 16 16	<pre>[X] EVENT_DesyncTracker_StartOfFrame EVENT_Game_GameTick EVENT_Game_DeltaTime EVENT_Player_Life EVENT_Player_Life EVENT_Input_Current_P1 EVENT_Input_Prev_P1 EVENT_Input_Prev_P2 EVENT_Input_Prev_P2 EVENT_Input_Prev_P2 [X] EVENT_UpdateGameTickCounter</pre>	0x7b 0x0 0x2 0x10 0x0 0x0 0x0 0x0 0x0 0x0 0x0 0x0 0x		18089 18090 18091 18092 18093 18094 18095 18096 18097 18098	0 1976 [LOG - 1976] [LOG - 1976] [LOG - 1976] [LOG - 1976] [LOG - 1976] [LOG - 1976] [LOG - 1976] 0 1976 0 1976	CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: - 1 1	FRAME: 1976 - DEBUG_TEXT: Serialize FRAME: 1976 - DEBUG_TEXT: Serialize (X) EVENT_DesyncTracker_EndOffr (X) EVENT_DesyncTracker_StartOf
18078 0 18079 0 18080 0 18081 0 18082 0 18083 0 18084 0 18085 0 18086 0 18086 0 18088 0 18088 0 18089 0	1976 1976 1976 1976 1976 1976 1976 1976	1 19 18 23 23 16 16 16 16 16 1 1	<pre>[X] EVENT_DesyncTracker_StartOfFrame EVENT_Game_GameTick EVENT_Game_DeltaTime EVENT_Player_Life EVENT_Player_Life EVENT_Input_Current_P1 EVENT_Input_Current_P1 EVENT_Input_Drev_P1 EVENT_Input_Drev_P2 EVENT_Input_Drev_P2 EVENT_Input_Prev_P2 [X] EVENT_UpdateGameTickCounter [X] EVENT_FMTRandomStream_GetDword</pre>	0x7b 0x0 0x2 0x10 0x10 0x0 0x0 0x0 0x0 0x0 0x0 0x7b 0x7d		18089 18090 18091 18092 18093 18094 18095 18095 18097 18098 18099	0 1976 [LOG = 1976] [LOG = 1976] [LOG = 1976] [LOG = 1976] [LOG = 1976] [LOG = 1976] [LOG = 1976] 0 0 1976 0 1976 0 1976 0 1976 0 1976 0 1976	CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: - 1 1 1	FRAME: 1976 - DEBUG_TEXT: Serialize FRAME: 1976 - DEBUG_TEXT: Serialize (X) EVENT_DeBUG_TEXT: Serialize (X) EVENT_DesyncTracker_EndOfFr (X) EVENT_DesyncTracker_StartOf EVENT_Game_GameTick
18078 0 18079 0 18080 0 18081 0 18082 0 18083 0 18084 0 18085 0 18086 0 18086 0 18088 0	1976 1976 1976 1976 1976 1976 1976 1976	1 19 18 23 23 16 16 16 16 16 16	<pre>[X] EVENT_DesyncTracker_StartOfFrame EVENT_Game_GameTick EVENT_Game_DeltaTime EVENT_Player_Life EVENT_Player_Life EVENT_Input_Current_P1 EVENT_Input_Prev_P1 EVENT_Input_Prev_P2 EVENT_Input_Prev_P2 EVENT_Input_Prev_P2 [X] EVENT_UpdateGameTickCounter</pre>	0x7b 0x0 0x2 0x10 0x0 0x0 0x0 0x0 0x0 0x0 0x0 0x0 0x		18089 18090 18091 18092 18093 18094 18095 18096 18097 18098	0 1976 [LOG = 1976] [LOG = 1976] [LOG = 1976] [LOG = 1976] [LOG = 1976] [LOG = 1976] [LOG = 1976] 0 0 1976 0 1976 0 1976 0 1976 0 1976 0 1976	CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: - CHANNEL: - 1 1 1	FRAME: 1976 - DEBUG_TEXT: Serialize FRAME: 1976 - DEBUG_TEXT: Serialize (X) EVENT_DesyncTracker_EndOffr (X) EVENT_DesyncTracker_StartOf
	18038 0 18038 0 18041 0 18042 0 18043 0 18044 0 18043 0 18044 0 18045 0 18046 0 18047 0 18048 0 18047 0 18058 0 18059 0 18055 0 18056 0 18057 0 18058 0 18059 0 18050 0 18052 0 18053 0 18055 0 18056 0 18057 0 18068 0 18069 0 18067 0 18070 0 18073 0 18074 0 18075 0 18074	18066 0 1976 18067 0 1976 18068 0 1976 18069 0 1976 18070 0 1976 18071 [LOG - 1976] Sta 18072 0 1976 18073 0 1976 18074 0 1976	18038 0 1976 22 18039 0 1976 22 18040 0 1976 22 18041 0 1976 22 18042 0 1976 22 18043 0 1976 22 18043 0 1976 22 18044 0 1976 2 18045 0 1976 2 18046 1976 2 1 18047 0 1976 2 18048 1976 2 1 18050 1976 2 1 18051 1976 2 1 18052 1976 2 1 18055 1976 2 1 18056 1976 2 1 18057 1976 2 1 18058 1976 2 1 18059 1976 2 1 18050 1976 2 1 18064 1976 2 <td>18088 0 1976 22 EVENT_Collision_Colnode_X 18089 0 1976 22 EVENT_Collision_Colnode_Z 18040 0 1976 22 EVENT_Collision_Colnode_Z 18041 0 1976 22 EVENT_Collision_Colnode_Y 18042 0 1976 22 EVENT_Collision_Colnode_Z 18043 0 1976 2 [X] EVENT_MCRM_AnimLocation_2 18044 0 1976 2 [X] EVENT_MCRM_AnimLocation_2 18045 0 1976 2 [X] EVENT_MCRM_MotionDelta 18046 0 1976 2 [X] EVENT_MCRM_MotionDelta 18047 0 1976 2 [X] EVENT_MCRM_IncommittedMotion 18048 0 1976 2 [X] EVENT_MCRM_IncommittedMotion 18049 0 1976 2 [X] EVENT_MCRM_IncommittedMotion 18050 0 1976 2 [X] EVENT_MCRM_Incotation 18050 0 1976 2 [X] EVENT_MCRM_Incotation 18050 0 1976 2 [X] EVENT_MCRM</td> <td>10037 0 1976 22 FVNIT_Collision_Colnode_X Oxid 10038 0 1976 22 FVNIT_Collision_Colnode_X Oxid 10040 0 1976 22 FVNIT_Collision_Colnode_X Oxid 18041 0 1976 22 FVNIT_Collision_Colnode_X Oxid 18042 0 1976 22 FVNIT_Collision_Colnode_X Oxid 18044 0 1976 22 FVNIT_Collision_Colnode_Z Oxid 18044 0 1976 2 [X] FVNIT_MCMM_AninLocation_2 Oxid 18045 0 1976 2 [X] FVNIT_MCMM_AninLocation_2 Oxid 18046 1976 2 [X] FVNIT_MCMM_AninLocation_2 Oxid Oxid 18047 0 1976 2 [X] FVNIT_MCMM_MotionDelta Oxid Oxid 18048 0 1976 2 [X] FVNIT_MCMM_MotionDelta Oxid Oxid 18051 0 1976 2 [X] FVNIT_MCMM_IncommittedNotion Oxid Oxid 18052 0 1976 2</td> <td>10037 0 1976 22 EVENT_Collision_Colnode_X 0x10 10038 0 1976 22 EVENT_Collision_Colnode_X 0x10 10040 1976 22 EVENT_Collision_Colnode_X 0x10 10410 1976 22 EVENT_Collision_Colnode_X 0x10 10441 1976 22 EVENT_Collision_Colnode_X 0x10 10443 1976 22 EVENT_Collision_Colnode_Y 0x10 10444 1976 22 EVENT_Collision_Colnode_Z 0x10 10445 1976 2 [X] EVENT_MCRM_Animicoation_2 0x2 10446 1976 2 [X] EVENT_MCRM_Animicoation_2 0x2 10446 1976 2 [X] EVENT_MCRM_Molinoheita 0.** 10446 1976 2 [X] EVENT_MCRM_IncommittedMolinon 0x1 10445 0 1976 2 [X] EVENT_MCRM_IncommittedMolinon 0x1 10550 1976 2 [X] EVENT_MCRM_IncommittedMolinon 0x2 0x1 10550 1976 2 [X] EVENT_MCRM_IncommittedMolinon 0x2</td> <td>18037 0 1976 22 EVENT_Collision_Colnode_Z 0h10 18047 18038 0 1976 22 EVENT_Collision_Colnode_X 0h10 18048 18038 0 1976 22 EVENT_Collision_Colnode_Z 0h10 18049 18041 0 1976 22 EVENT_Collision_Colnode_Z 0h10 18041 18042 0 1976 22 EVENT_Collision_Colnode_Y 0h10 18051 18044 0 1976 22 EVENT_Collision_Colnode_Y 0h10 18052 18045 0 1976 22 EVENT_Collision_Colnode_Y 0h10 18053 18046 0 1976 2 IXI EVENT_MCCM Animiccention_2 0h1 18055 18046 0 1976 2 IXI EVENT_MCCM Molicohalia 0h1 18055 18047 0 1976 2 IXI EVENT_MCCM Molicohalia 0h1 18066 18050 0 1976 2 IXI EVENT_MCCM Molicohalia 0h1 18066 18051 0 1976 IXI EVENT_</td> <td>19037 1976 22 FVENT_collision_Colnode_Z 0x10 19047 0 1976 19038 0 1976 22 FVENT_collision_Colnode_X 0x10 19049 0 1976 19040 1976 22 FVENT_collision_Colnode_Z 0x10 19059 19976 19041 1976 22 FVENT_collision_Colnode_Z 0x10 19050 1976 19042 1976 22 FVENT_Collision_Colnode_Z 0x10 19050 1976 19043 1976 22 FVENT_Collision_Colnode_Z 0x10 19050 1976 19044 1976 2 KJNENT_MCRU_AninaLocation_Z 0x10 19050 1976 19045 1976 2 KJNENT_MCRU_AninaLocation_Z 0x11 19055 1976 19046 1976 2 KJNENT_MCRU_Anonomitteddforin 0x11 19055 1976 19051 1976 2 KJNENT_MCRU_Anonomitteddforin 0x11 19056 1976 19055 1976 2 KJNENT_MCRU_Anonomitteddforin 0x11 19056 1976</td> <td>18087 0 1976 2.2 FVMT_Collision_Colmode_Z 0.10 18047 0 1976 2.2 18088 0 1976 2.2 FVMT_Collision_Colmode_Y 0.10 18048 0 1976 2.2 FVMT_Collision_Colmode_Y 0.10 18068 0 1976 2.2 FVMT_Collision_Colmode_Y 0.10 18068 0 1976 2.0 18047 0 1976 2.0</td>	18088 0 1976 22 EVENT_Collision_Colnode_X 18089 0 1976 22 EVENT_Collision_Colnode_Z 18040 0 1976 22 EVENT_Collision_Colnode_Z 18041 0 1976 22 EVENT_Collision_Colnode_Y 18042 0 1976 22 EVENT_Collision_Colnode_Z 18043 0 1976 2 [X] EVENT_MCRM_AnimLocation_2 18044 0 1976 2 [X] EVENT_MCRM_AnimLocation_2 18045 0 1976 2 [X] EVENT_MCRM_MotionDelta 18046 0 1976 2 [X] EVENT_MCRM_MotionDelta 18047 0 1976 2 [X] EVENT_MCRM_IncommittedMotion 18048 0 1976 2 [X] EVENT_MCRM_IncommittedMotion 18049 0 1976 2 [X] EVENT_MCRM_IncommittedMotion 18050 0 1976 2 [X] EVENT_MCRM_Incotation 18050 0 1976 2 [X] EVENT_MCRM_Incotation 18050 0 1976 2 [X] EVENT_MCRM	10037 0 1976 22 FVNIT_Collision_Colnode_X Oxid 10038 0 1976 22 FVNIT_Collision_Colnode_X Oxid 10040 0 1976 22 FVNIT_Collision_Colnode_X Oxid 18041 0 1976 22 FVNIT_Collision_Colnode_X Oxid 18042 0 1976 22 FVNIT_Collision_Colnode_X Oxid 18044 0 1976 22 FVNIT_Collision_Colnode_Z Oxid 18044 0 1976 2 [X] FVNIT_MCMM_AninLocation_2 Oxid 18045 0 1976 2 [X] FVNIT_MCMM_AninLocation_2 Oxid 18046 1976 2 [X] FVNIT_MCMM_AninLocation_2 Oxid Oxid 18047 0 1976 2 [X] FVNIT_MCMM_MotionDelta Oxid Oxid 18048 0 1976 2 [X] FVNIT_MCMM_MotionDelta Oxid Oxid 18051 0 1976 2 [X] FVNIT_MCMM_IncommittedNotion Oxid Oxid 18052 0 1976 2	10037 0 1976 22 EVENT_Collision_Colnode_X 0x10 10038 0 1976 22 EVENT_Collision_Colnode_X 0x10 10040 1976 22 EVENT_Collision_Colnode_X 0x10 10410 1976 22 EVENT_Collision_Colnode_X 0x10 10441 1976 22 EVENT_Collision_Colnode_X 0x10 10443 1976 22 EVENT_Collision_Colnode_Y 0x10 10444 1976 22 EVENT_Collision_Colnode_Z 0x10 10445 1976 2 [X] EVENT_MCRM_Animicoation_2 0x2 10446 1976 2 [X] EVENT_MCRM_Animicoation_2 0x2 10446 1976 2 [X] EVENT_MCRM_Molinoheita 0.** 10446 1976 2 [X] EVENT_MCRM_IncommittedMolinon 0x1 10445 0 1976 2 [X] EVENT_MCRM_IncommittedMolinon 0x1 10550 1976 2 [X] EVENT_MCRM_IncommittedMolinon 0x2 0x1 10550 1976 2 [X] EVENT_MCRM_IncommittedMolinon 0x2	18037 0 1976 22 EVENT_Collision_Colnode_Z 0h10 18047 18038 0 1976 22 EVENT_Collision_Colnode_X 0h10 18048 18038 0 1976 22 EVENT_Collision_Colnode_Z 0h10 18049 18041 0 1976 22 EVENT_Collision_Colnode_Z 0h10 18041 18042 0 1976 22 EVENT_Collision_Colnode_Y 0h10 18051 18044 0 1976 22 EVENT_Collision_Colnode_Y 0h10 18052 18045 0 1976 22 EVENT_Collision_Colnode_Y 0h10 18053 18046 0 1976 2 IXI EVENT_MCCM Animiccention_2 0h1 18055 18046 0 1976 2 IXI EVENT_MCCM Molicohalia 0h1 18055 18047 0 1976 2 IXI EVENT_MCCM Molicohalia 0h1 18066 18050 0 1976 2 IXI EVENT_MCCM Molicohalia 0h1 18066 18051 0 1976 IXI EVENT_	19037 1976 22 FVENT_collision_Colnode_Z 0x10 19047 0 1976 19038 0 1976 22 FVENT_collision_Colnode_X 0x10 19049 0 1976 19040 1976 22 FVENT_collision_Colnode_Z 0x10 19059 19976 19041 1976 22 FVENT_collision_Colnode_Z 0x10 19050 1976 19042 1976 22 FVENT_Collision_Colnode_Z 0x10 19050 1976 19043 1976 22 FVENT_Collision_Colnode_Z 0x10 19050 1976 19044 1976 2 KJNENT_MCRU_AninaLocation_Z 0x10 19050 1976 19045 1976 2 KJNENT_MCRU_AninaLocation_Z 0x11 19055 1976 19046 1976 2 KJNENT_MCRU_Anonomitteddforin 0x11 19055 1976 19051 1976 2 KJNENT_MCRU_Anonomitteddforin 0x11 19056 1976 19055 1976 2 KJNENT_MCRU_Anonomitteddforin 0x11 19056 1976	18087 0 1976 2.2 FVMT_Collision_Colmode_Z 0.10 18047 0 1976 2.2 18088 0 1976 2.2 FVMT_Collision_Colmode_Y 0.10 18048 0 1976 2.2 FVMT_Collision_Colmode_Y 0.10 18068 0 1976 2.2 FVMT_Collision_Colmode_Y 0.10 18068 0 1976 2.0 18047 0 1976 2.0

Press F1 for help



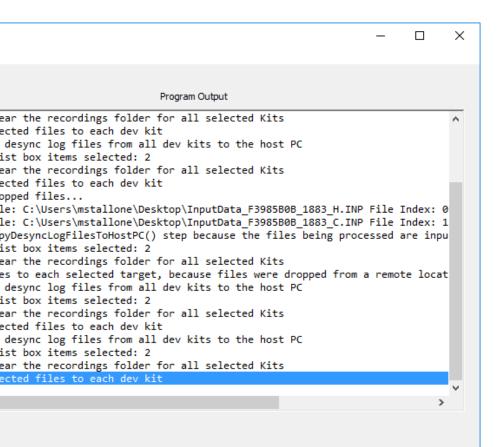
Default ANSI code page 59 removals · 67 insertions · 32 changes Ln 18074 of 18984 Col 1



Desync tools

- General desync detection and logging
- Replay files
- DesyncUtil
- NRSSoak

- 101	ync Util Version: 1.5.0.9 D:\dcf2dev\root\Binari ew Settings Tools	25
	Target System Build Configuration	
	PS4 Development	Ready to clear the records Copying selected files to Copying all desync log fil
	(C)ompare Most Recent Logs	Number of list box items s Ready to clear the records Copying selected files to
	(P)layback Most Recent Input Logs	Accepted dropped files DragQueryFile: C:\Users\ms DragQueryFile: C:\Users\ms
	(G)et Desync Logs from Hydra	Skipping CopyDesyncLogFile Number of list box items
	Convert .b64 file to .log	Ready to clear the records Copying files to each sele Copying all desync log fil
	(L)aunch Selected Kits	Number of list box items s Ready to clear the record
	(K)ill Selected Kits	Copying selected files to Copying all desync log fil Number of list box items
_	Cancel Current Job	Ready to clear the recordi Copying selected files to
	Exit	٢





Low-Level Lessons Learned

- Limit mutable state
- Prefer handles over pointers where performance allows
- Avoid shared ownership of mutable resources
- Avoid work in constructors/destructors
- Lean on memcopies/buffer swaps instead of dynamic fixup





High-Level Lessons Learned

- Design game systems to drive visual state, not depend on it
- Design systems to update with variable time steps
 - Parametrically is even better

GDC

- Everyone should work with debug rollback systems enabled
- Defer processing until after the rollback window if reasonable
- Bog is no longer a function of a single frame



depend on it eps

ems enabled if reasonable



Future work

- Multithread gameplay script
- Extend state based serialization
- Simplify particle serialization/simulation (parametric?)
- Game state separation from the visual state
- Add rollback support for more systems





Questions?

NETHESREFIUM STUDIOS is hiring

Mike Stallone mstallone@netherrealm.com



