Cubes All The Way Down

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GAME DEVELOPERS CONFERENCE



GDC

About Me

- Started 3D programming in VB6 & Truevision3D ~ 2001
- Started working with Phil Fish on FEZ in April 2007
- FEZ gets 2 noms and 1 win (Visual Arts) at IGF'08
- Bacc. in Computer Science at UQÀM in late 2008
- Worked full-time since then at Polytron
 - FEZ is first commercial title and full-time "industry" "job"

About FEZ



- 2D/3D Exploration Puzzle Platformer ("mystroidvania")
- Pixel art where the pixels are 3D *trixels*
- Platforming in 2D, but across all 4 orthographic views
- Built in XNA/C# from the start
 - Spanned 5 XNA versions, from 1.0 to 3.1!

Game Footage



World Structure

- Big branching mess, 157 areas total
- Each is an isolated level
 - But level transitions are made "seamless"





How are levels "cut up"?

- Art- and level-production wise, tiles are easier
- Plain old 2D tilemap doesn't work : we need 3D tiles
 - ...triles?

• 16x16x16 voxels (*trixels*) chosen as an arbitrary fixed size

"Nature" Trile Set (302 triles)



Texturing Triles

- Per-trixel coloring?
 - Implies good integrated painting tools

- Cubemaps! (*freebloods*) **F R B L U D**
 - Triles need to be convex
 - Cubemaps are 16x16x6 32bpp = 6kb uncompressed!



Modelling Triles

• First trile concepts made in Google Sketchup (2007)





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Trile Sculpting





Blocky But Detailed

- Average of 136 polygons per trile
- Typical scene : 50,000 polygons
 - But anywhere from ~5000 to ~250,000





Mesh Simplification

- Extrapolate contiguous surfaces from trixels
- For each surface,
 - Enumerate biggest rectangles in that surface
 - Each rectangle becomes a plane





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Building Levels in "Fezzer"



Completed level in final Fezzer



Building Fezzer...



Feature tracking

- Google Docs all the way!
- Sprints planned 1 week to 1 month ahead
 - Do basic feature first, revisit & polish later

IDESCRIPTION PROCESS START END MOTES MOTE MOTES MOTE MOTES MOTE MOTES		A	В	с	D	E		А	в	с	D	E	F	G
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7 7	6	One-click trile rotation randomizer		4/27/2009	4/28/2009		6		breakable blocks	mine level variant	done	12/4/2008	12/4/2008	phil
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9 Variable trile collision size (height) done 6/12/209 6/1/2009 6/1/	8	Variable trile collision size (width + depth)		5/4/2009	5/11/2009	Including dynamic entities like crates (pickup/throw support, stacking)	8		stalagmites	falling stalagatites	done	4/20/2009	4/20/2009	phil
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12 Serving any life groups in the editor done 5/19/2009 group of state load in the isolation mode, but yst dynaw in carres (mode, but yst dynaw in carres (mo	11	Remove/optimize LINQ queries for pickup objects		5/8/2009	5/8/2009	Only remaining garbage is caused by dictionary key/value iterators	11		chain reaction brock		in progross	412012000	412012000	print
13 Focus on selection nokeypress in eldor done 66/2009	12	Save/load trile groups in the editor		5/19/2009	5/20/2009	.grp.sdl files, act like selected triles but grouped (manipulated with the	12	Design	level design		to do			phil
14 Store suffaces in the set intermediate files done - / / / / / / / / / / / / / / / / / / /	13	Focus on selection on keypress in editor		5/6/2009	5/7/2009	Like the trile isolation mode, but just plays with camera (press Enter in	13							
10 Clamps of stale code from last summer done April 2009 to July 2009 Composite trile instances (done), wird switch support, probabyle tries instances (done), wird switch support instances (done), wird switch support, probabyle tries instances (done), wird switch swi	14	Store surfaces in trile set intermediate files				For faster loading in editor & compilation	14	Animations	dripping water		to do			annabelle
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17 Animated planes support done 5/2/2009 Gold 2009	16	Redesign/simplification of event system		Late June 2009		Especially the interface	16		big explosion		to do			annabelle
18 Basic content pipeline & editor support for NPCs done 6// 2009 6// 10/2009 Portperties dialog is still missing, but more pressing things avait 18 0	17	Animated planes support		5/27/2009	6/3/2009	Source is an animated GIF, behaves like a planar art object	17		falling stalagtite		to do			annabelle
9 Vertically scrolling textures on triles & at objects done	18	Basic content pipeline & editor support for NPCs		6/4/2009	6/10/2009	Properties dialog is still missing, but more pressing things await	18		5 5					
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30 If there are three trile layers and you are between two of them, the hacknowned/fiberenword/wall-hungsing ones herzerk 30 1 1	29	Elastic collisions		5/11/2009	5/18/2009	Applied to some kinds of particles and non-collidable objects	29		tnt crates					
Three-laver background problems done background/wall-hugging ones berzerk 31	30					If there are three trile layers and you are between two of them, the	30							
		Three-laver background problems				background/foreground/wall-bugging goes berzerk	31							

+ E GLOBAL VILLAGE NATURE INDUSTRIAL ZU UNDERGROUND AQUADUCTS DATES TECHNOLOGY

+ 📃 VILLAGE NATURE MINE ZU RUINS INDUSTRIAL CRYSTAL CAVE TRANSITION CAVE 02 GRAVEYARD TECHNOLOGY GEEZER'S HOUSE Bugs/To-

Designer us. Programmer Dynamic

- Phil dictated design, but I implemented
 - As the programmer, YOU know what's possible
 - Time-wise, performance-wise, and in regards to your abilities
- You can always say no, but it's a discussion
 - FEZ is a "game d'auteur", designer associates with it deeply
 - It's all about mutual respect

A note on Version Control

- Holy shit you guys, use version control.
- Used local NAS with batch file madness for whole 2009
 - Lost content, overwritten files, flaky backups
 - "I'm just one guy" and "I have infinite undo levels" are not good reasons
 - Remote SVN/Git/Hg servers are cheap, and they WILL save your ass

Thanks Nathan @ Capy for convincing us to make the jump!

How do we draw all that stuff?

- Lots of tiny blocks
- Geometry gets pretty dense
- Potentially lots of overdraw in 2D views
- Ideally 60 FPS on Xbox 360

\Rightarrow By culling and batching efficiently



Rendering Triles : Culling

- Orthographic views, usually looking into an axis
 - Peel the frontmost layer(s)
 - At most two layers if mid-rotation
- Cull within view frustum
- When moving, only invalidate triles for the screen's moving border (don't recull everything unless necessary)



How Culling Works

- Cell content is cached
- For each screen cell
 - Start at camera depth
 - Mark trile to be drawn
 - Walk into screen
 - Stop at solid, non-seethrough & non-offset trile



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Culling Disabled



Culling Enabled (~3X less triles)



Rendering Triles : Batching

- Draw calls are expensive
- All triles are independent (so indie)
 - Can't just throw everything at the GPU
- \Rightarrow Batching is a must
 - But dynamic culling means dynamic batching...
 - Is there a simple way?

Randaring Trilas : Botching Instancing

- Lots of instances of a single trile type in a level
- Few things specific to an instance
 - XYZ Position, Y rotation : 4 single-precision floats
- vfetch instancing on Xbox 360

≈ Shader Model 3.0 Hardware Instancing on PC

• Max. 256 instances of the same trile per draw call

How-to : GPU Instancing (Xbox)

- A static vertex buffer
 - Vertex data of the template trile (lightweight)
- A dynamic index buffer
 - One set of indices for each instance
 - Offset indices as if you'd have as many clones in vertex buffer
- An instance data buffer
 - Actually a 4D vector or 4x4 matrix array in vertex shader constants
 - Contains the instance-specific data

Xbox Instancing Vertex Shader

0.

0,

0,

1

```
int vertexIndex = mod(IN.Index, VertexCount);
int instanceIndex = IN.Index / VertexCount;
```

// Index is an automagic vertex input semantic
// VertexCount is uniform parameter fed by app

```
asm
```

```
{
```

};

```
vfetch position, vertexIndex, position0
vfetch normal, vertexIndex, normal0
vfetch textureCoordinate, vertexIndex, texcoord0
```

// vfetch magic gets appropriate vertex data

```
float4 InstanceData = InstanceDataArray[instanceIndex];
```

```
float sinPhi, cosPhi;
sincos(InstanceData.w, sinPhi, cosPhi);
float4x4 instanceMatrix =
```

{

```
cosPhi,0,-sinPhi,0,1,0,sinPhi,0,cosPhi,InstanceData.xyz,
```

// W component contains Y-axis rotation angle
// Recompute instance transformation matrix

};

Other Stuff : Planes/Decals

• Where sclupting doesn't matter, or sprite animations











Other Stuff : Art Objects

• For small overlapping details, or unique bigger landmarks



DOT the Tesseract

- 4D hypercube fairy
- Continually rotates about the X-W plane
 - Done in C# (on the CPU)
 - 4x4 matrix works for rotation
- Faux 4D to 3D projection
 - Further out in W axis = smaller in 3D
- Rendered in orthographic projection like everything else
- 96 vertices, 144 triangles (no intersection in 4D space)







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Collision Management

- Triles are the collision map
 - Each trile has a type
 - Can be per-face too!
- Four types
 - Immaterial (blades of grass)
 - No collision (background elements)
 - Top-collide (most platforms)
 - All-collide (blocking boundaries; rare)



Invisible Collision Triles

- Art objects need to collide too
 - But they're not made of triles!

- Filled with invisible triles
 - No collision, or
 - Top-only collision



Collision Lookup

- Similar as the culling process
 - Collide with what you see!
 - Peel back from view
 - Keep peeling back if hitting
 - Immaterial triles (i.e. grass strands)
 - Non-grid-aligned triles

Otherwise, point-to-line with first solid trile edge found (three points), one axis at a time.



Non-Grid-Aligned?

- Triles can be moved arbitrarily
 - Stored in cell that contains its center
- Collision tests look up neighbours
 - Only one, away from cell's center
 - Only if no hit in current cell
 - Once found, point-to-line (using appropriate size & offset of the trile)



Tests...

- Scaling can also be arbitrary
- As long as triles are no smaller than half of Gomez's size (limitation of using
 - point collision)



How Gomez moves around

• Movement is along on the view plane

- Depth correction rules
 - Gomez should stay visible, always
 - Gomez should never walk in mid-air
- Otherwise, don't touch his depth



• During view rotations, movement & time are suspended

Background Mode

- If Gomez is behind the level post-rotation
 - IGF'08 build : Panic & QTE!

 \Rightarrow Stressful, kills the mood, generally dumb

- Final build
 - Silhouette rendering
 - Low-pass music
 - Limited actions





Lighting Pre-Pass

- Per-face direct/diffuse light
- Ambient light = sky background color
 - Cloud shadows end up blueish
- Shadows and additional lights added (in screen-space)
- All done in a lighting pre-pass
- Blended in Modulate2X mode
 - so that it can light up and shadow



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Time Of Day Lighting



World Interactions

- Gomez can :
 - Grab/push/pull objects
 - Rotate parts of the world independently
 - Make blocks crumble under his weight
 - Grab ledges all around platforms
 - Interact with one-off puzzle objects
 - Swim in water & drown in toxic liquids
 - AND MUCH MUCH MORE
- 56 different "action classes" control his behaviour



Action "Classes For States"

- All player action classes derive from a base abstract class
- Not all mutually exclusive
 - "Fall" is an action that is evaluated as long as there's gravity
- They know how to chain from state to state

```
protected virtual void TestConditions()
protected virtual void Begin()
protected virtual void End()
protected virtual bool Act(TimeSpan elapsed)
   return false;
```

Example : WalkRun.cs

```
protected override void TestConditions()
    switch (PlayerManager.Action)
           case ActionType.Sliding:
           case ActionType.Idle:
           case ActionType.Teetering:
           case ActionType.Grabbing:
           case ActionType.Pushing:
           case ActionType.LookingAround:
               // If grounded and pressed movement keys
               if (PlayerManager.Grounded && InputManager.Movement.X != 0 &&
                   PlayerManager.PushedInstance == null)
                      PlayerManager.Action = ActionType.Walking;
               break;
```

Example : WalkRun.cs

```
protected override void IsActionAllowed(ActionType type)
{
    return type == ActionType.Running || type == ActionType.Walking;
}
protected override bool Act(TimeSpan elapsed)
{
    // Transform input to physics impulses in a helper class
    MovementHelper.Update((float)elapsed.TotalSeconds);
    if (MovementHelper.Running)
           PlayerManager.Action = ActionType.Running;
    else
           PlayerManager.Action = ActionType.Walking;
```

Additional Flags for Actions

```
public static class ActionTypeExtensions
    public static bool IsAnimationLooping(this ActionType type)
           switch (action) { /* ... */ }
    public static bool DisallowsRespawn(this ActionType type)
           switch (action) { /* ... */ }
    }
    public static bool PreventsRotation(this ActionType type)
           switch (action) { /* ... */ }
    /* ... */
```

Actors : Dynamic World Entities

- Spinning blocks, moving platforms, ladders, interactive structures, etc.
- Hardcoded behaviours with flags or parameters set in the editor
- Tradeoff for not having proper scripting support



Scripting System

- Designer-friendly UI (no code!)
- Event-based

🖶 Scripts Browser

Id	Trigger	Condition	Action
10	Level.Start		Dot.SpiralAround(True, False), Dot.Say(DOT_TRIAL_A, True, False), Dot.Say(DOT_TRIAL_B, T
11	Volume[6].Enter	Game.GetLevelState != JUMP, Game.GetLevelState != LOOK,	Game.ShowScroll(TUTO_VINE, 5, True, True)
4	Volume[3].Enter		Level.ChangeLevelToVolume(MEMORY_CORE, 0, True, True)
6	BitDoor[38].Open		Volume[3].SetEnabled(True, False)
7	Level.Start		Camera.SetPixelsPerTrixel(3), Volume[3].SetEnabled(False, False)
8	Level.Start	Level.FirstVisit = False	Sound.ChangeMusic()
9	Level.Start	Level.FirstVisit = True	Sound.ChangeMusic(Clear Skies)
13	Gomez.Jumped	Game.GetLevelState = JUMP	Game.CloseScroll(TUTO_JUMP), Game.ShowScroll(TUTO_LOOKAROUND, 5, True, False), Gi
14	Gomez.LookedAround	Game.GetLevelState = LOOK	Game.Wait(1), Game.CloseScroll(TUTO_LOOKAROUND), Game.ShowScroll(ROTATE_INSTRU
15	Camera.Rotated	Game.GetLevelState = ROTATE	Game.Wait(1), Game.CloseScroll(ROTATE_INSTRUCTIONS), Game.SetLevelState()
23	Volume[7].Enter		Game.ShowScroll(TUTO_GRAB_LEDGE, 0, True, True)
20	Volume[3].Enter		Game.ShowScroll(TUTO_ENTER_DOOR, 0, True, True)
21	Gomez.EnteredDoor		Game.CloseScroll(TUTO_ENTER_DOOR)
22	Gomez.ClimbedVine		Game.Wait(1), Game.CloseScroll(TUTO_VINE)

Script Editor

- Triggers
- Conditions
- Actions

• And lots of WinForms controls

riggers (WHEN)	Conditions (IF, optional)	Actions (WHAT)
Trigger Remove Clone Add Gomez.LookedAround	Condition Remove Clone Add Game.GetLevelState = LOOK	Action Remove Clone Add Game.Wait(1) Game.CloseScroll(TUTO_LOOKAR Game.ShowScroll(ROTATE_INSTRU Game.SetLevelState(ROTATE)
Entity Type : Gomez 💌 Identifier : (global) Pick	Entity Type : Game Identifier : (global) Pick	Entity Type : Game Identifier : (global) Pick
Event : LookedAround 💌	Property : GetLevelState Operator : = Value : LOOK	Operation : Wait
cript Properties		Param. Name Value seconds 1
Name : Untitled Timeout : 0.0 🗼 seconds Use Timeout	Crite-Time Level-Wide Only Disabled Triggerless Ignore End-Triggers	Value : Browse Resource

Script Example : DOT interaction

• Warn the player of a particular mechanic in a level using DOT

When Level Starts, (Start event on Level static entity) (blocking actions executed in sequence)

- Remove player controllability
- DOT says a couple lines
- Move the camera to Volume #3 (point of interest)
- DOT says more stuff
- DOT comes back and hide
- Player regains control

This script happens once in the game :

	Trigg	ers (W	HEN)						
	Trigg	er	Remo	ove	Clor	e A	dd		
	Level	.Start							
Actio	ns (W	HAT,)						
Actio	on	Rem	nove) (c	lone	A	dd		
Gom	iez.Se	tCan	Cont	rol(False)		[+
Dot.	Say(D	OT_F	RACT	AL_	A, Tr	ue, I	a		
Dot.	Say(D	OT_F	RACT	AL_	B, Tr	ue, I	a		
Volu	ime[3]	.Mov	eDot	Wit	hCa	mera	0		
Dot.	Say(D	OT_F	RACT	AL_	C, Fa	alse,	F	ſ	_
Dot.	Say(D	OT_F	RACT	AL_	D, Fa	alse,	F		ŧ
Dot.	Come	Back	And	lide	(Tru	e)			
Gom	iez.Se	tCan	Cont	rol((rue				

Script Propert	ies	
Schpenopen		
Name :	Untitled	✓ One-Time

Scripting Interfaces

```
// Properties, for conditions
bool FirstVisit { get; }
```

// Operations, for actions (can be running over time à La coroutine)
[Description("Smoothly changes to a new water height")]
LongRunningAction SetWaterHeight(float height);

Level Format



- At design-time, serialized from objects to SDL
 - Similar to YAML or JSON, but better integrated with .NET
 - Tweakable by hand
 - Error resilient
 - Ignores unknown elements
 - Elements can be marked as optional
- At compile-time, binary format for performance & filesize
 - No automatic serialization, reflection is too slow on Xbox

SDL Looks Like This —

- Output much more concise than equivalent XML serialization
- Serialization tags in data objects

```
public string Name { get; set; }
public TrileFace StartingPosition { get; set; }
public Vector3 Size { get; set; }
[Serialization(Optional = true)]
public float BaseDiffuse { get; set; }
[Serialization(CollectionItemName = "Trile")]
public Dictionary<TrileEmplacement, TrileInstance> Triles;
```

```
level type="FezEngine.Structure.Level, FezEngine" {
   name "ARCH"
   startingPosition {
       face "Front"
        id 16 6 5
    size 30F 49F 35F
   baseDiffuse 1F
   baseAmbient 0.35F
   haloFiltering true
    blinkingAlpha false
   waterHeight 11F
   skyName "WATERFRONT"
   trileSetName "Untitled"
   volumes {
       volume key=0 {
              orientations "Front"
              actorSettings {
                  farawayPlaneOffset 5F 1F
              from 3F 26F 15F
              to 4F 28F 16F
```

MARCH 5-9, 2012 WWW.GDCONF.COM

Music System

- Written on-top of XACT
- Allows infinite, dynamic track-based songs
- Scriptable
 - Level/player events can mute/unmute tracks
- Works with time of day

Song Editor	
Song Name Cycle	Rename
Overlay Loops Cycle ^ Aeolian_Antecedent_i Cycle ^ Aeolian_Bass_4Bars Cycle ^ Aeolian_Consequent Cycle ^ Aeolian_MinArp_8B Cycle ^ Aeolian_MinArp_8B Cycle ^ Aeolian_Triplets_9Bar Cycle ^ Dorian_Trecedent_3 Cycle ^ Dorian_Consequent.i Cycle ^ Dorian_Consequent.i Cycle ^ Dorian_Consequent.i Cycle ^ Dorian_Ostinato_2ba Cycle ^ Dorian_Ostinato_2ba Cycle ^ Dorian_Ostinato_2bars Cycle ^ Dorian_Antecedent_i Cycle ^ Locrian_Antecedent_i Cycle ^ Locrian_Consequent.i Cycle ^ Locrian_Consequent_i Cycle ^ Locrian_Consequent_i Cycle ^ Locrian_Consequent_i Cycle ^ Locrian_Consequent_i Cycle ^ Locrian_Consequent_i Cycle ^ Locrian_Triplets_9bars Cycle ^ Locrian_Triplets_9bar: **	Selected Loop Properties Loop Filename Cycle ^ Aeolian_MainArp_8B;, Trigger between after every 0 all 16 bars Fractional time and loop between 1
Base Properties Tempo Time Signature 140 💭 4 🕎 / 4	Random One-at-a-Time Ordering Custom Ordering (comma-separated)
Assemble Chord E_maj Shard Notes D2 E2 A2 B2	Preview
	Accept Cancel

Music System In Action

• 🐗 "Puzzle-solving music" @ daytime

Track	Initial Delay	Duration	Inter-Play Delay
Main Arp	None	8 bars	[0, 16] bars
Counter Arp	4 bars	8 bars	[0, 16] bars
Ostinato	8 bars	4 bars	[0, 16] bars
Bass	8 bars	4 bars	[0, 24] bars
Antecedent	16 bars	3 bars	[0, 16] bars
Triplets	16 bars	9 bars	[0, 16] bars
Consequent	20 bars	3 bars	[0, 16] bars

Night is less dense, very different sounding and still randomized : 4

Xbox-spacific Optimization

- XNA on the Xbox 360 = .NET Compact Framework
 - Garbage collection every 1Mb allocated, unpredictable, blocking
 - Rules of thumb : avoid LINQ, dynamic allocations
- Draw calls are expensive : batching is essential, instantiate ALL THE THINGS
 - Defer as many operations as possible to vertex shaders instead of CPU
 - Otherwise, multithread; 5 cores at your disposal
- HDD access is slow, flash memory access is worse!
 - Pre-load all content, avoid disk access later on
 - You probably have more RAM than content (in FEZ, totally)

Tools : CLR Profiler

- Excellent, free memory profiler
- Allocations graphs, memory usage by class
- Good for identifying real-time garbage & why load-times stall



Tools : CPU Profiler

- Any one you want (AQTime, dotTrace...), but I like ANTS Performance Profiler a lot
- Absolutely essential for finding bottlenecks



Tools : Analyzing Memory Profiler

- CLR Profiler is good for garbage generation, but isn't very helpful for leaks
- I used the SciTech .NET Memory Profiler
- Heap snapshot comparisons
- Insight on possible problems
- Leaky objects are identified and their creation point given

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XDK Tools

All other tools worked with a PC build; what if stuff only happens on Xbox?

- xbWatson
 - Make your own measurements and output to console
- PIX
 - Frame-by-frame teardown of what's costly
 - Excellent for inspecting the draw calls & shaders
- CPU Performance Profiler in the XDK ultimately useless
 - Made for native code, not .NET games

XNA on XBLA : My Experience

- Long dev cycle meant struggle with upgrades
- No native library allowed, only .NET : can be problematic
- Some boilerplate TCR stuff handled, but still a lot to think about
- No symbols for debugging .NET assemblies in Release builds

But...

- .NET, C#, XNA and WinForms make engine & tools dev way easier
- Transition from PC to Xbox all in all fairly painless
- It's all about comfort : I couldn't have done FEZ in C++

A lesson is learned...?

- I don't think there's a way around it : a first game is HARD to finish
 - Especially if you care a lot about it
 - And let's face it, FEZ is a huge game
- Early showing was a double-edged sword
 - But later PAX/Fantastic Arcade showing were great motivators & feedback tools
- Feature creep, constant feeling that finish line is 3-6 months away
 - Making short-form "game jam" games helped learn scope control

If I had to do it again...

- Use middleware (Unity?), or hire an engine programmer
- Have real scripting support and educate artists about it
- Hot-reloadability of scripts and content edits
 - Even if C# compilation is fast, back & forth is huge waste of time
- Don't be afraid to scrap prototype code
 - 4-year-old bugs coming back to haunt you : it sucks
 - Realize you're doing a big, long project, and that it's worth the effort

That's all, folks!

- Thanks for coming!
- Questions?

