Simple and Powerful Animation Compression

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Contributors

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- Luke Mamacos, consultant

- Thank you Eidos Montreal!

Presentation outline

- A bit of context

Presentation outline

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- The classic solutions

Presentation outline

- A bit of context
- The classic solutions

- Our special blend!

A bit of context

- The game engine used by Rise of the Tomb Raider (2015)

- Same compression algorithms since ~1996!
  - Used in dozens of AAA titles
  - Based on linear key reduction

A bit of context

\+ Good size

\- Slow decompression

\- Sub-par accuracy

The problem

- Cinematic clips
  - Need high accuracy
  - Size matters

The problem

- Cinematic clips
  - Need high accuracy
  - Size matters
- Ever higher need for accuracy
  - 40% clips used weak compression
  - Time is the enemy

The problem

- Legacy code not ideal
  - Very old, aged poorly
  - Not streaming friendly
  - Nobody wants to get near it

Design goals

- Solve cinematics first
  - Through streaming (if we need to)
- Keep it simple
  - Time budget: 20 days

Design goals

- Fast decompression
- High accuracy

Design goals

- Best effort
  - Small size
  - Nothing to tweak
  - Supersede everything

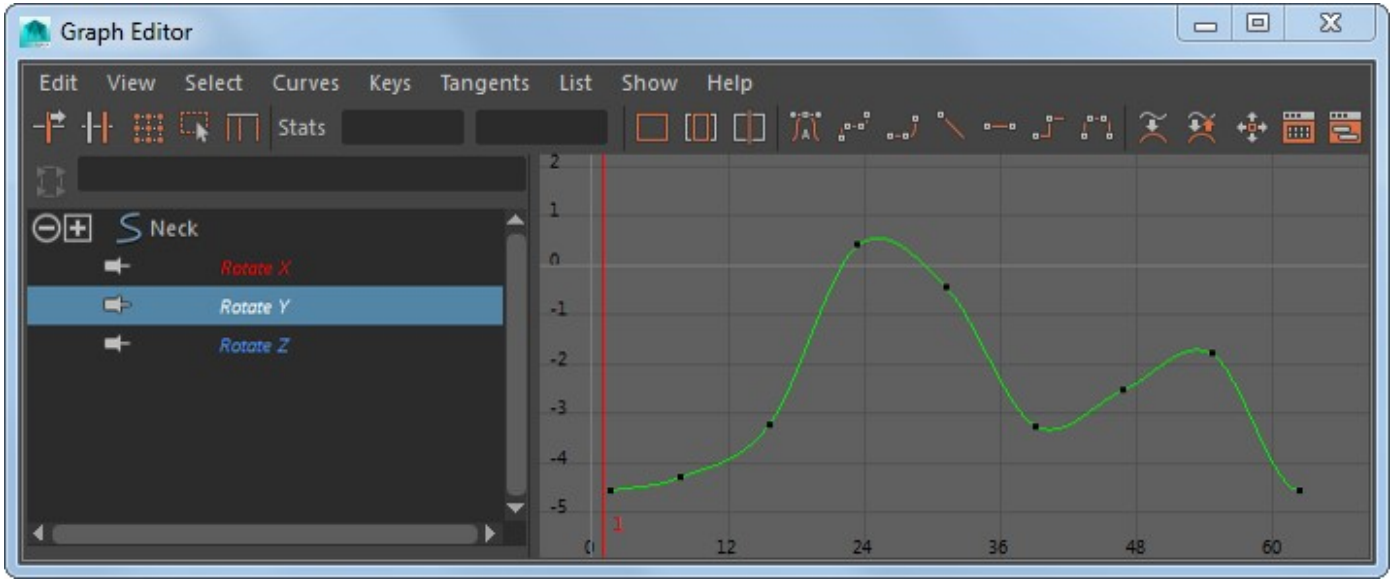
Most common algorithm families

- Signal processing
- Curve fitting
- Linear key reduction
- Simple key quantization

Signal processing

- E.g. wavelets
- Too complex
- See blog!

Curve fitting



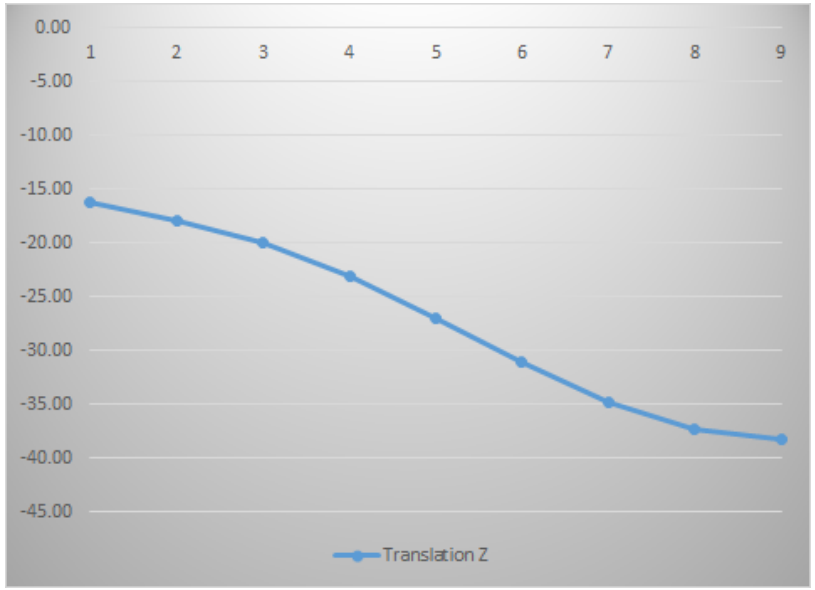
Curve fitting

- Pros
  - Sensible choice
  - Very compact

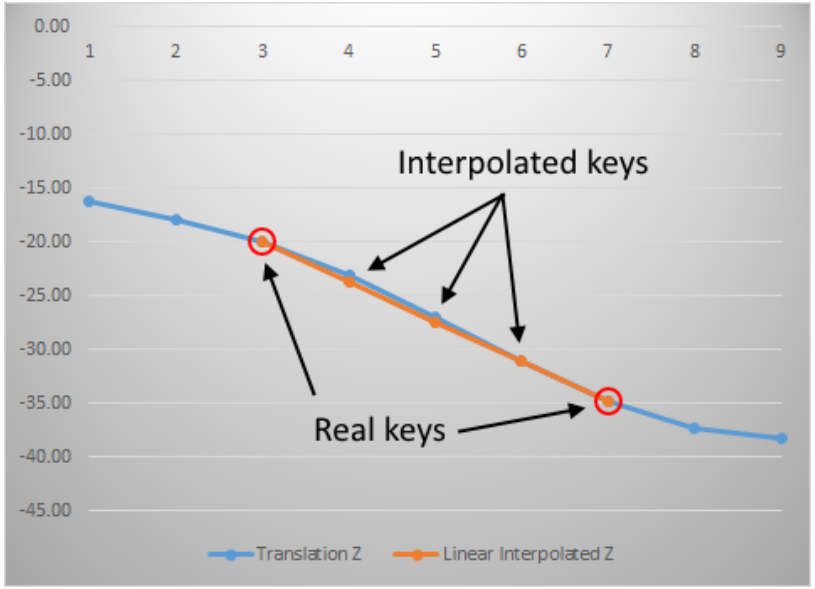
Curve fitting

- Cons
  - Not accessible
  - Slower decompression
  - Medium complexity
  - Not great for mocap

Linear key reduction



Linear key reduction



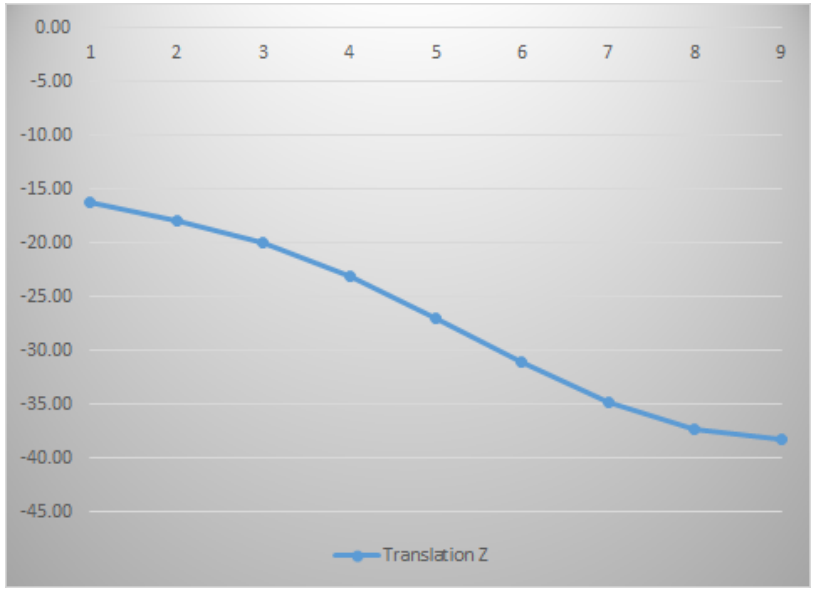
Linear key reduction

- Pros
  - Reasonably simple
  - Reasonably compact
  - Similar to legacy impl.

Linear key reduction

- Cons
  - Similar to legacy impl.
  - Slow decompression
  - Not great for mocap

Simple quantization



Simple quantization

- Pros
  - Dead simple
  - Very fast
  - Solid foundation

Simple quantization

- Cons
  - Not very compact

- **Good enough!**

Our solution

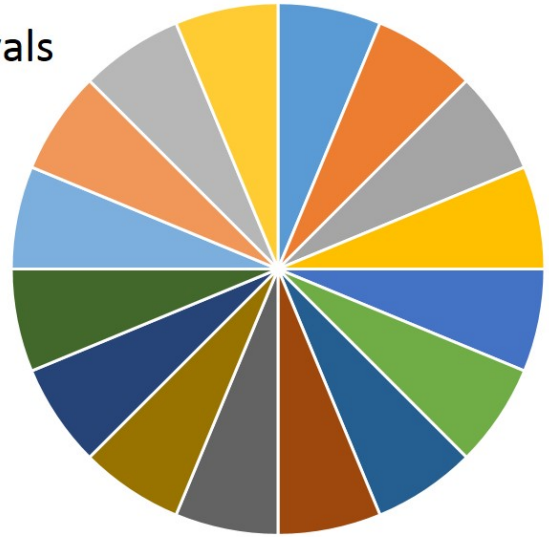
- Range reduction
- Uniform segmenting
- Constant tracks
- Quantization

Range reduction

- Tracks in terms of ranges
- E.g. my elbow rotates by 120° in a clip
  - Theoretical range: 360°
  - Effective range: 120°

Range reduction

4 bits = 16 intervals

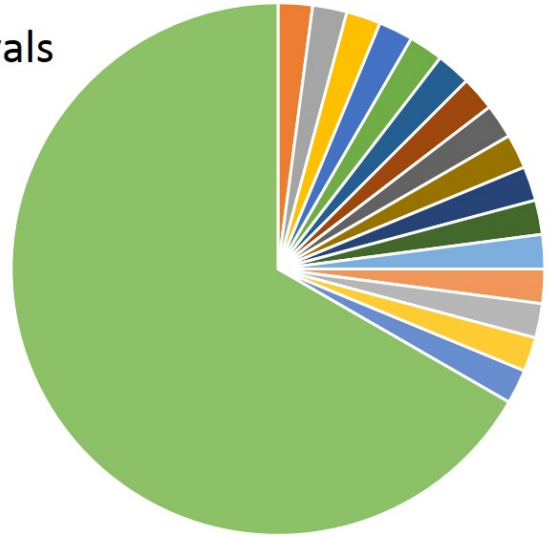


Precision: 22.5°

Range: 360°

Range reduction

4 bits = 16 intervals



Precision: 7.5°

Range: 120°

Range reduction

- Some overhead
  - Range Minimum
  - Range Extent
- Normalizes our values
- Range expansion is trivial
  - (normalized value * extent) + min

Range reduction

- 6 scalar values = full track range
  - 3 components * (min, extent)
- Clip metadata
  - 6x floats = 24 bytes
  - **per animated track**

Range reduction

- More accuracy => can be more lossy
- Bad for short clips

- **Worth it!**

Uniform Partitioning

- Split clips in blocks of 16 key frames

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Uniform Partitioning

- Split clips in blocks of 16 key frames
  - Fast and easy seeking
  - Easy streaming
  - Range reduction per block

Uniform Partitioning

- Block metadata
  - 6x 8 bit = 48 bits = 6 bytes
  - **per animated track**

  - ***Lossy normalization!!***

Constant Tracks

- For our main characters (~3500 clips)

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  - Bones: 65% constant, 45% bind pose

Constant Tracks

- For our main characters (~3500 clips)
  - Bones: 65% constant, 45% bind pose
  - Tracks: 87% constant, 79% bind pose

Constant Tracks

- Per clip, 1 bit **per track**:
  - Is it bind pose?
  - Yes? Drop it!

Constant Tracks

- Per clip, 1 bit **per track**:
  - Is it bind pose?
  - Yes? Drop it!
- Per clip, 1 bit **per track**:
  - Is it constant?
  - Yes? Keep 1 key! (3x floats)

Quantization

- Hard coded, 16 bits

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Quantization

- Hard coded, 16 bits
- Best common rate per clip
- Best rot/trans/scale rate per clip
- Best rot/trans/scale rate per block
- ***Best individual track rate per block***

Variable bit rate

- Ideal for:
  - Hierarchical data
  - Exotic tracks
  - Temporal coherence
  - Everything!

Quantization details

- 16 possible bit rates

- Bit rates: 0, 3, 4, .., 16, 23

Quantization details

- 23 was a bad & naïve choice
  - Same as float mantissa minus sign bit

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  - Same as float mantissa minus sign bit
  - De-quantization requires our integer to be representable as a floating point number
  - ***32 bit float = 6 significant digits*** ☹
  - 19 might be a better choice, measure!

Quantization details

- 0 => track is constant in block
  - We don’t need range information

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- 0 => track is constant in block
  - We don’t need range information
  - Store our constant key instead!

Compression

- Almost everything is fairly trivial
- Only complex step is bit rate selection

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- Almost everything is fairly trivial
- Only complex step is bit rate selection
  - Measuring accuracy
  - Need a smart heuristic

Measuring accuracy

- **Important!**
  - Our algorithm iterates with it
  - We compare our results to others with it

Measuring accuracy

- **Important!**
  - Our algorithm iterates with it
  - We compare our results to others with it
- Often overlooked and poorly implemented!

Measuring accuracy

- Three important criteria:
  - Account for hierarchy
  - Account for aggregate transform
  - Account for visual mesh

Measuring accuracy

- Hierarchy is important!
  - Error accumulates down hierarchy
  - Don’t use local space metrics!
  - Use object space

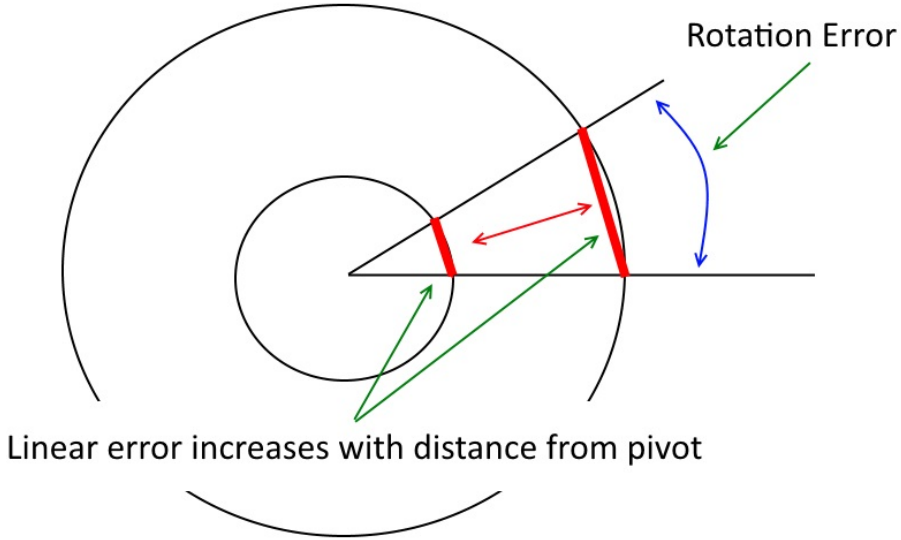
Measuring accuracy

- Aggregate error is important!
  - Don’t measure error with leaf bone position
  - It ignores rotation/scale contribution!

Measuring accuracy

- Skeleton error != visual mesh error
  - Skeleton is never visible, visual mesh is
  - With rotation & scale, error increases with distance from bone

Measuring accuracy



Measuring accuracy

- Vertex displacement on the visual mesh is the true measure of accuracy
  - Skinning == metric function
  - Satisfies all 3 criteria

Measuring accuracy

- But…
  - It is way too slow
  - Mesh information might not be available
  - Some bones have no skinned vertices

Measuring accuracy

- Use virtual vertices instead!
  - Approximates skinning
  - Satisfies all 3 criteria
  - Intuitive tweaking: distance from bone
  - Output is object space displacement error

Measuring accuracy

- We use:
  - 3 cm for normal bones
  - 1 m for high accuracy bones

Bit Rate Selection

- Huge search space!
  - Need smart heuristic

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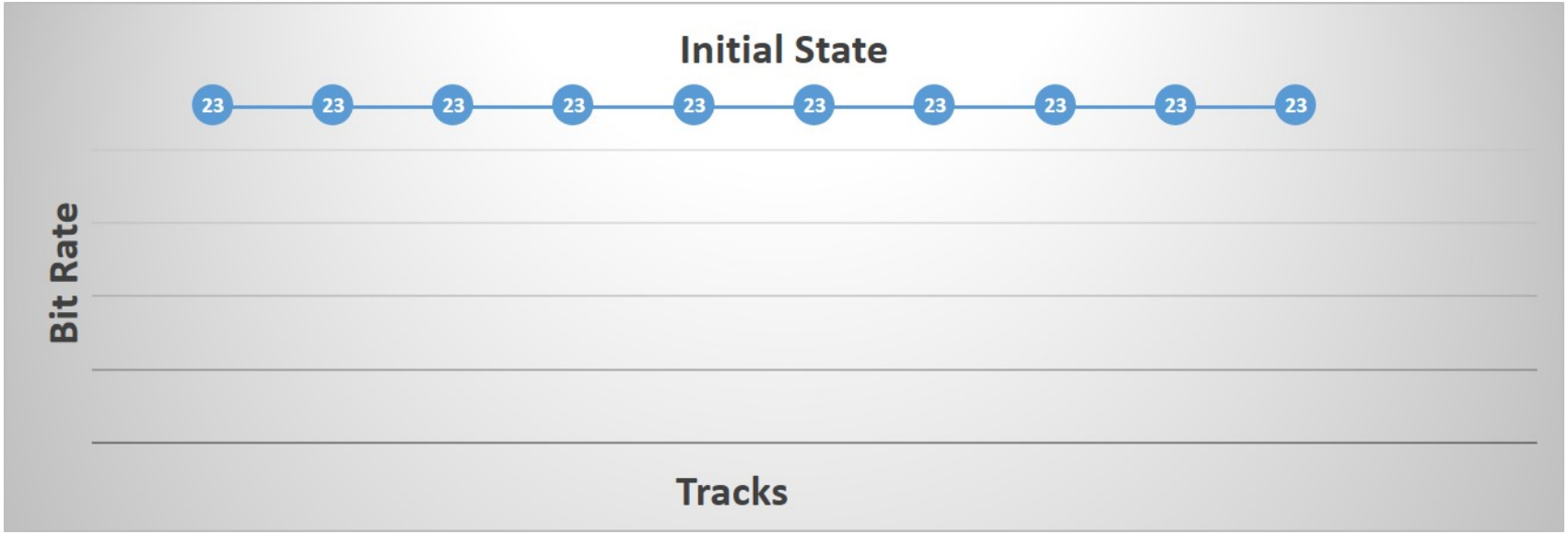
- First pass finds an approximate solution

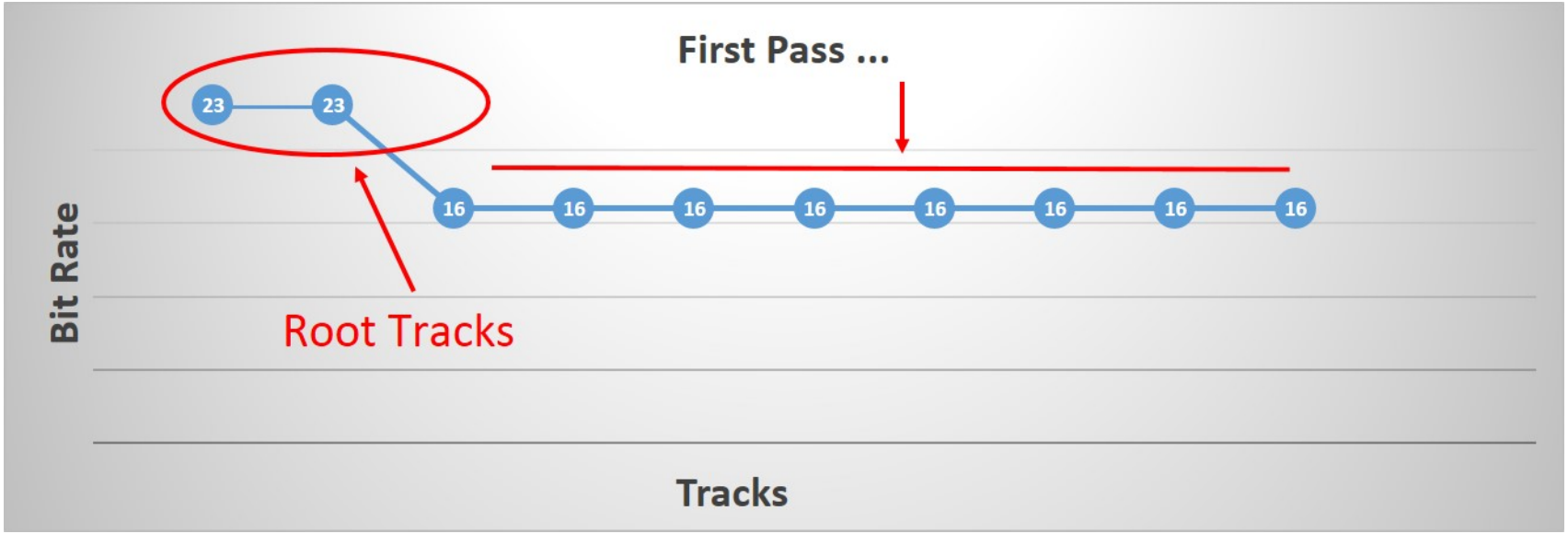
Bit Rate Selection

- Huge search space!
  - Need smart heuristic
- First pass finds an approximate solution
- Second pass refines to local minimum

Bit Rate Selection



Bit Rate Selection



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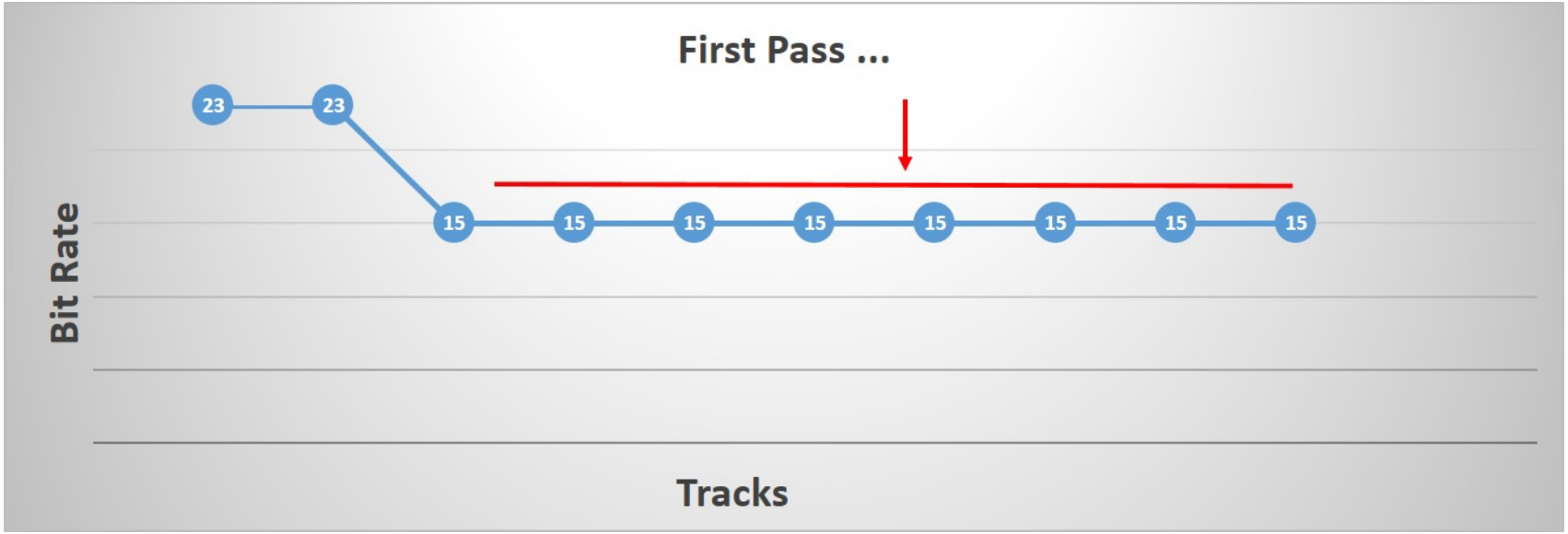
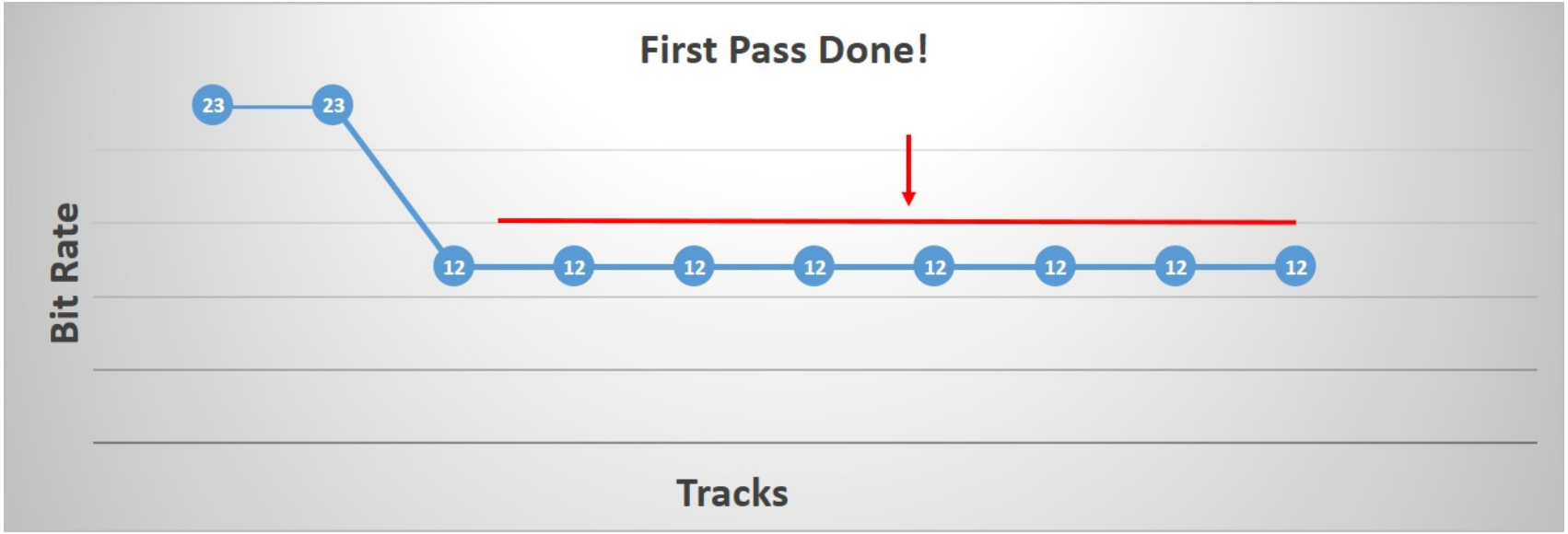
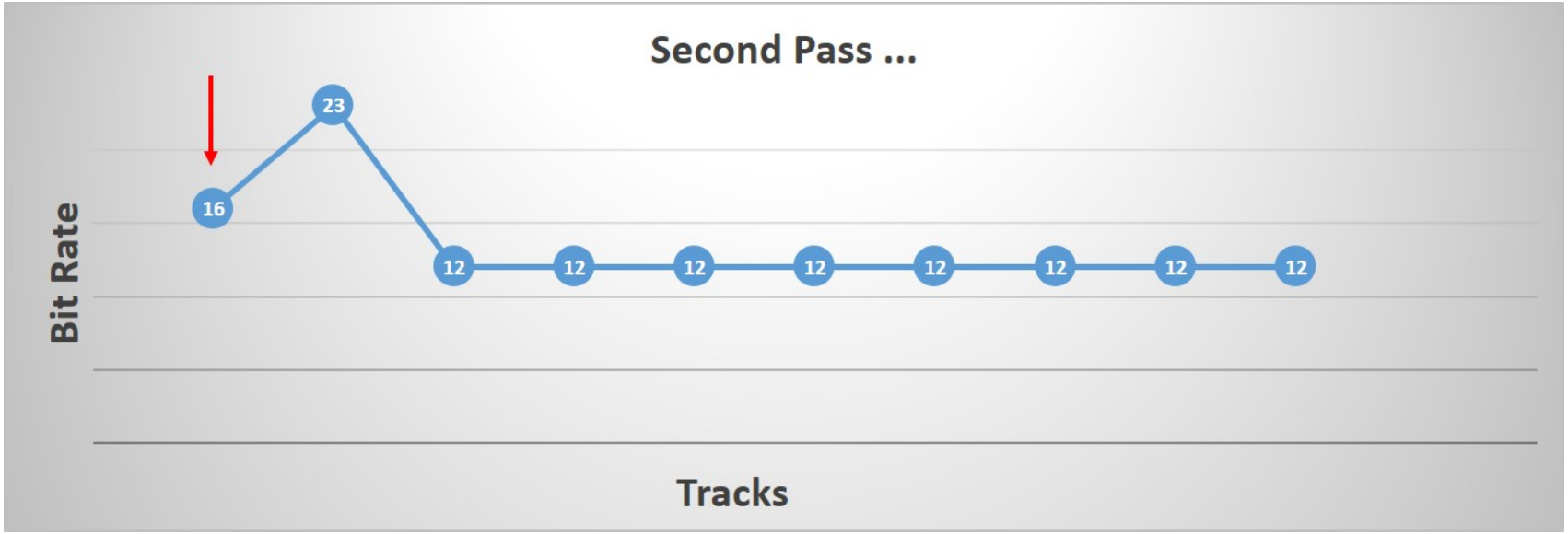


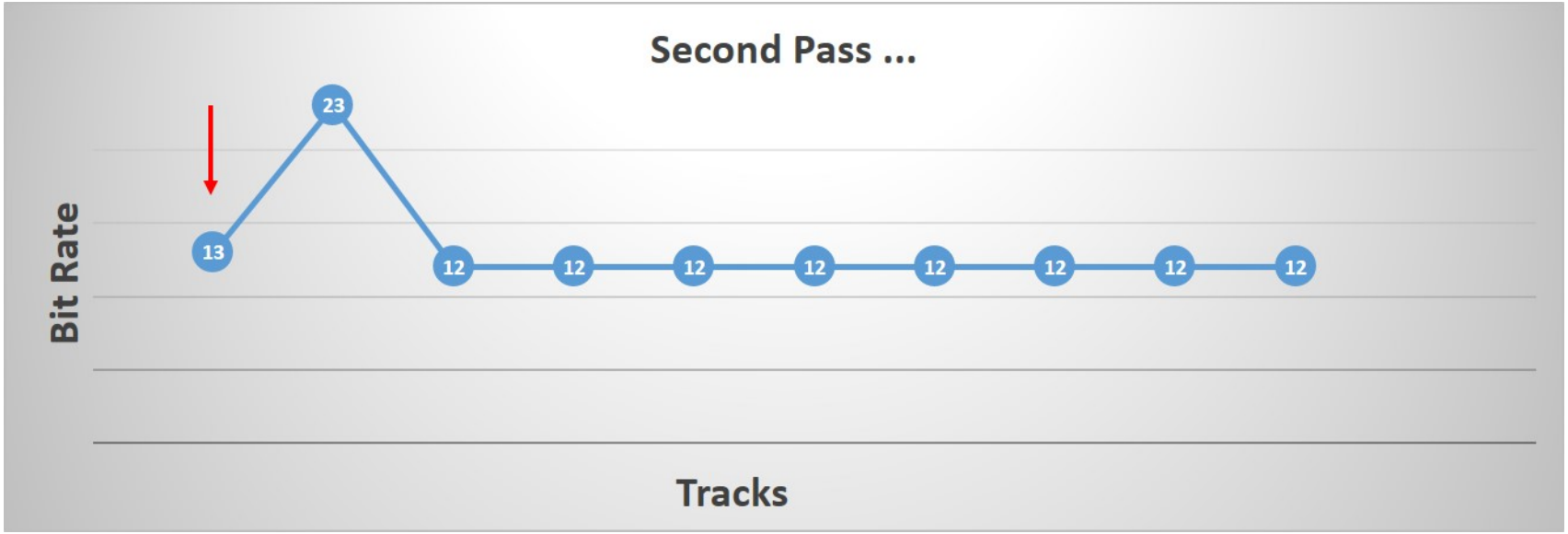
Bit Rate Selection



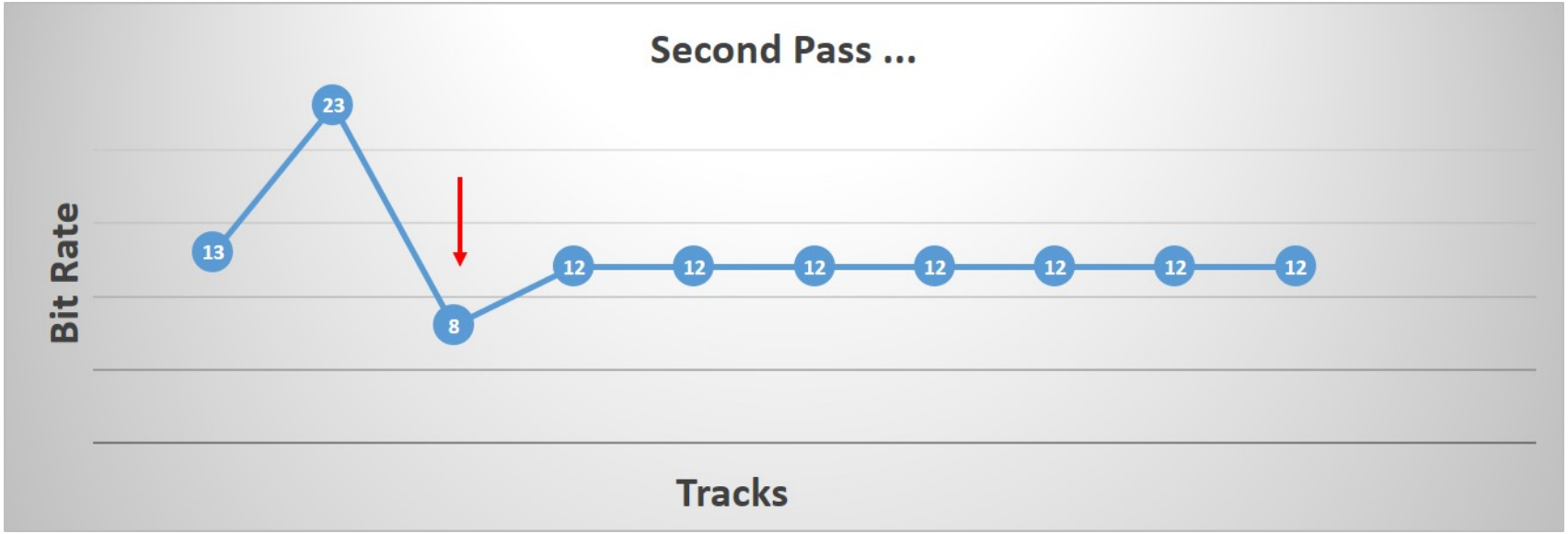
Bit Rate Selection



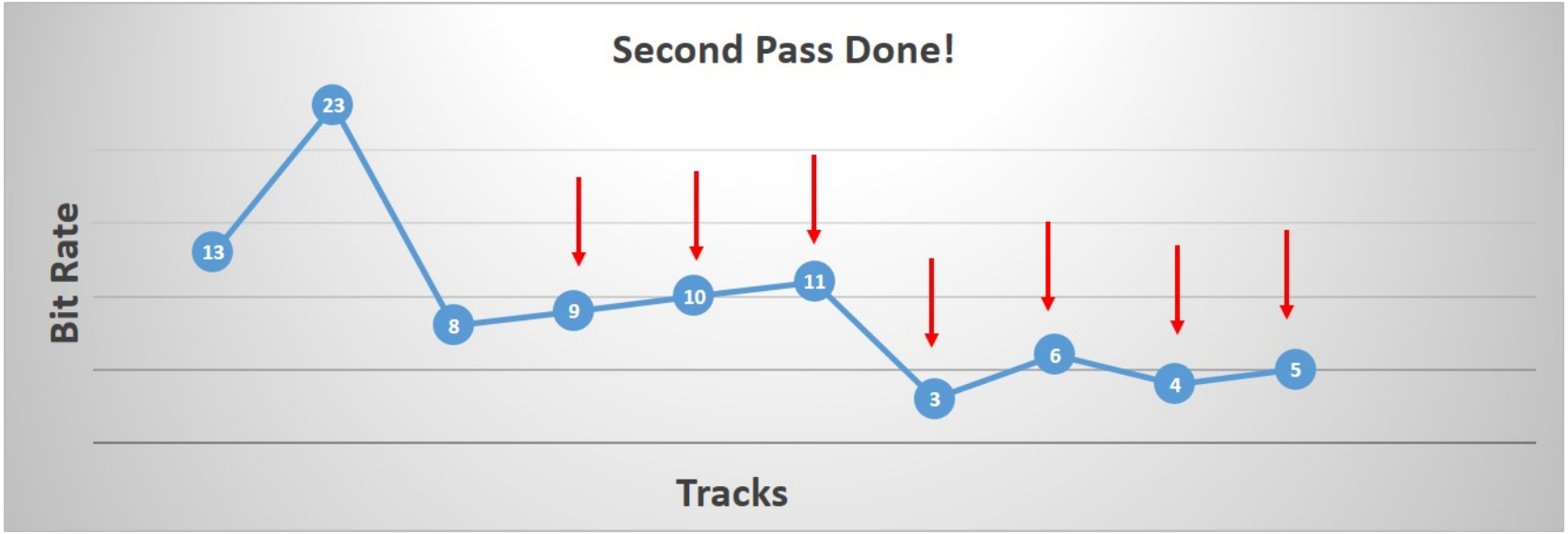
Bit Rate Selection



Bit Rate Selection



Bit Rate Selection



Bit Rate Selection

- We minimize the bit rate
- We maximize the error

- Threshold is important!
  - 1 mm is too high

Bit Rate Selection

- Hardcoded threshold: ***0.1 mm***
  - **Sub-millimeter accuracy!**

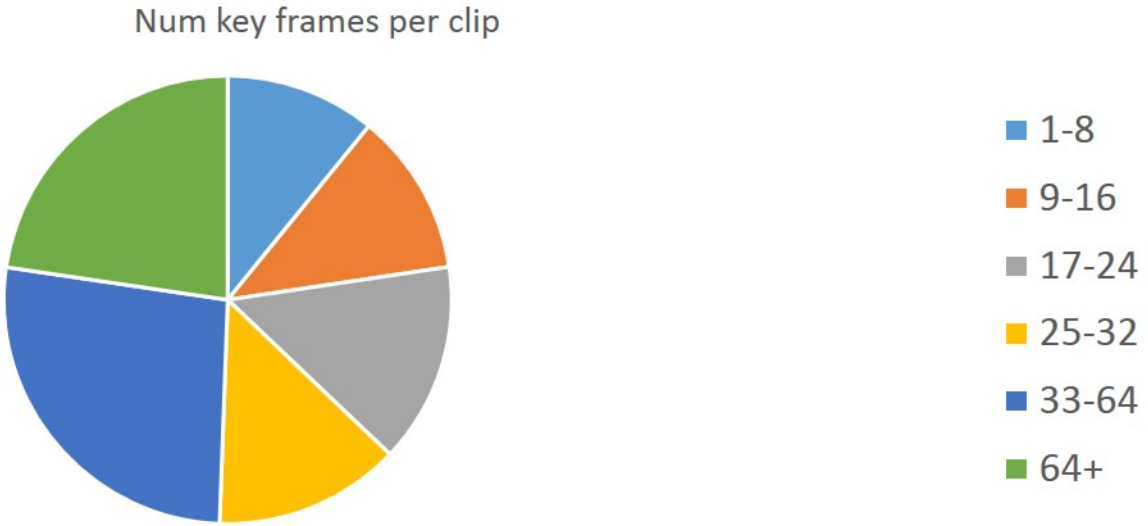
The results

- Aggregated
- Concrete examples

Aggregate Results

- 3900 clips (various characters)
- Compression time:
  - 3.2 hours, single threaded
  - 10 minutes, multi threaded
- Sum of clip lengths:
  - 5.4 hours @ 30 FPS

Aggregate Results



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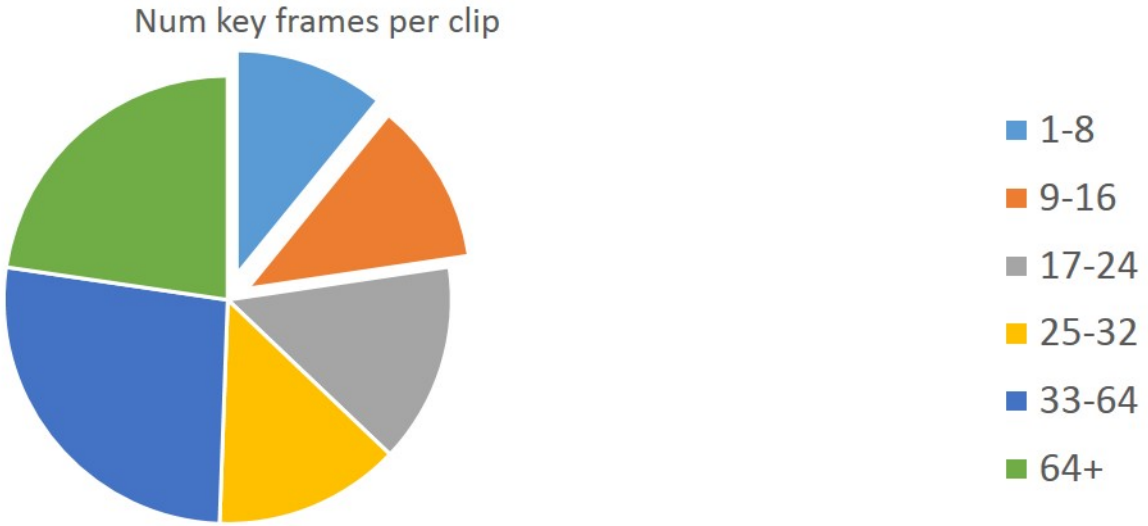

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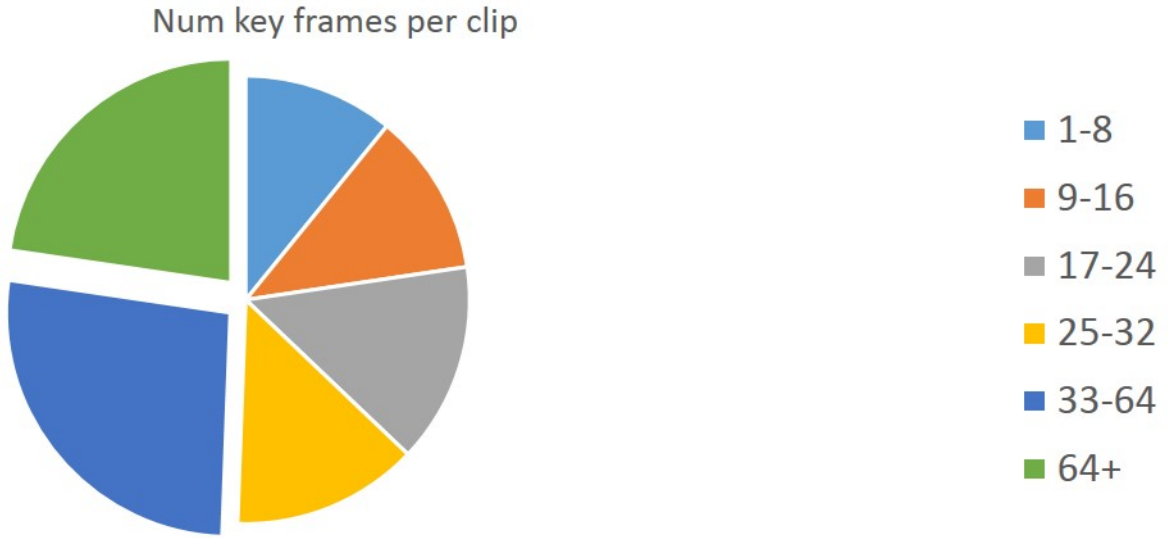
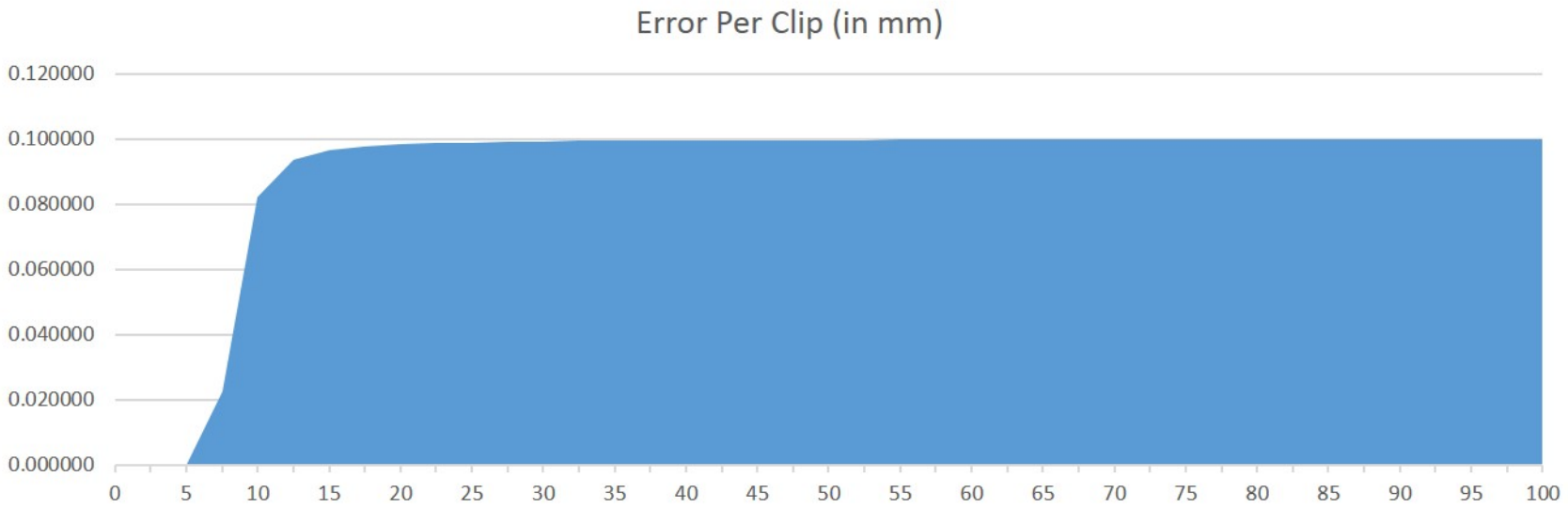


Aggregate Results

- Total size on disk: 168.4 MB
  - Legacy size: 300.0 MB
- Average number of animated tracks:
  - 56.0 per clip

Aggregate Results



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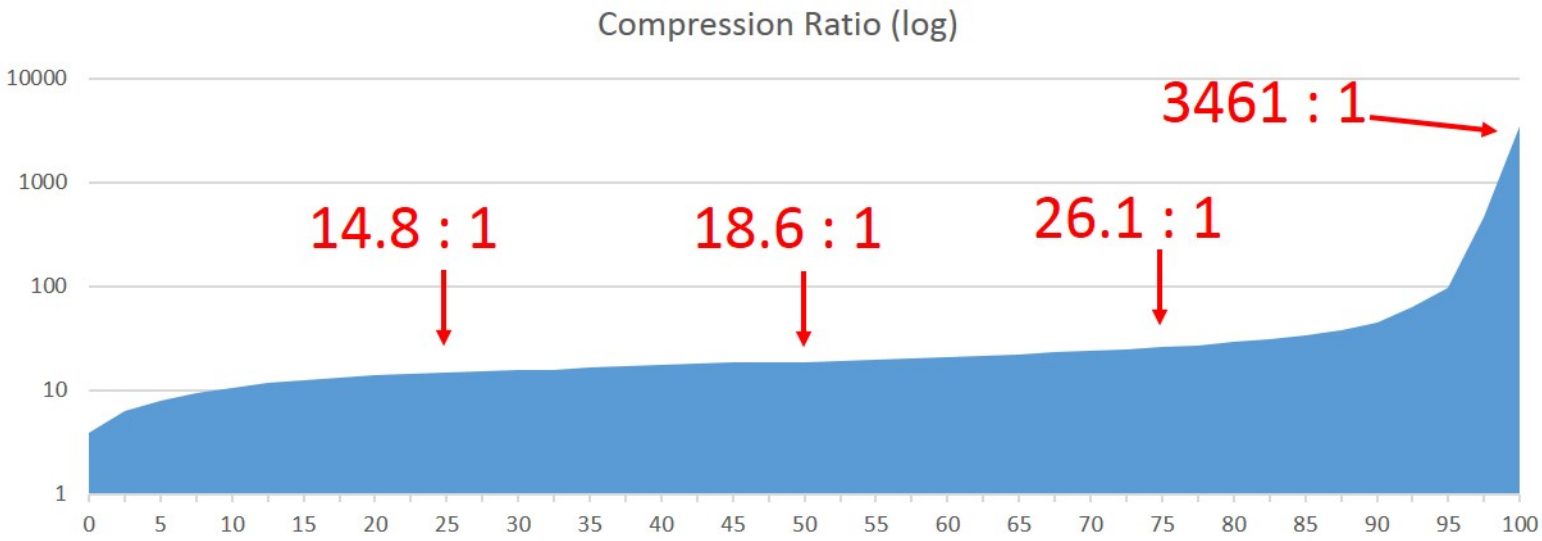


Raw Clip Size

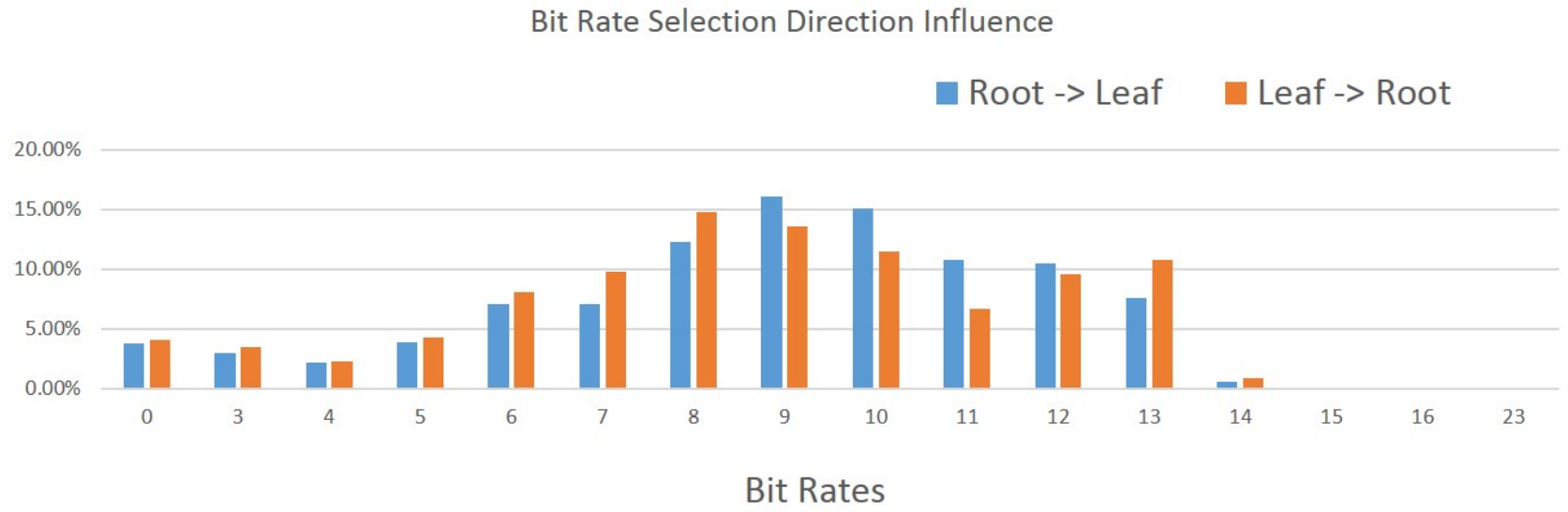
- Compression ratio is meaningless
- Unless raw size is consistent!

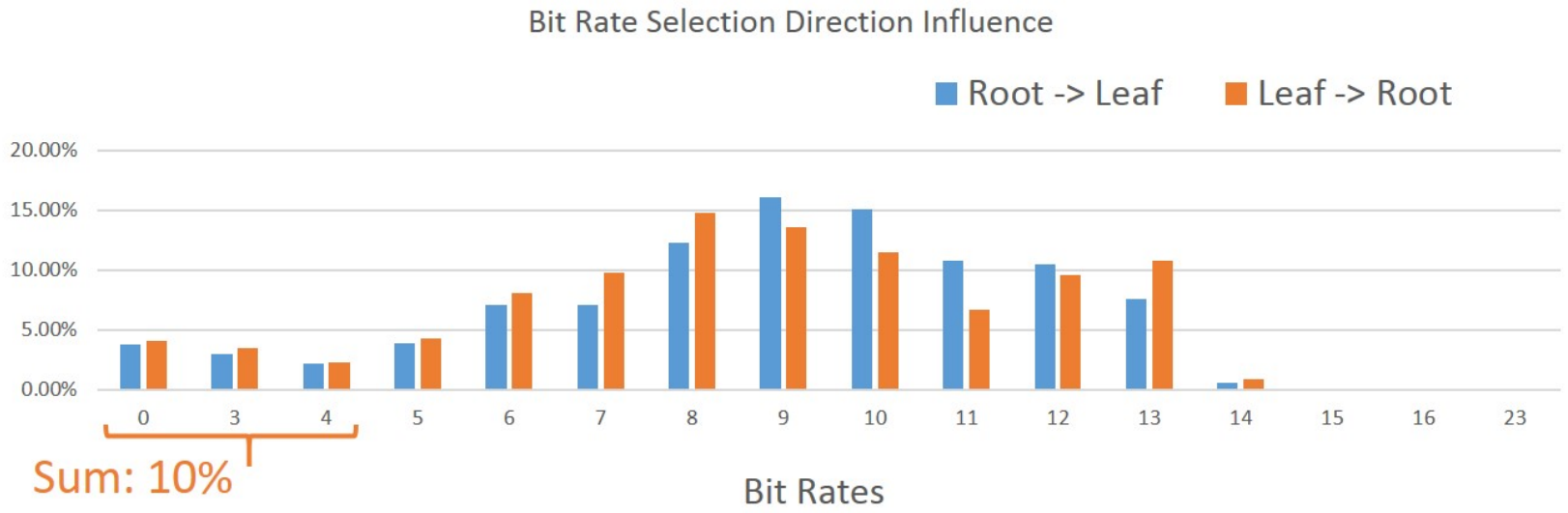
Raw Clip Size

- Raw size =
  # key frames * # bones * 36 bytes

Raw Clip Size

- 1 track key = 3 floats = 12 bytes
- 1 bone key = 3 track keys = 36 bytes
- 1 key frame with 140 bones = 140 bone keys = 4.9 KB
- 30 key frames = 147.7 KB


Bit Rate Selection Direction Influence
Root -> Leaf
Leaf -> Root
20.00%
15.00%
10.00%
5.00%
0.00%
0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
23
Bit Rates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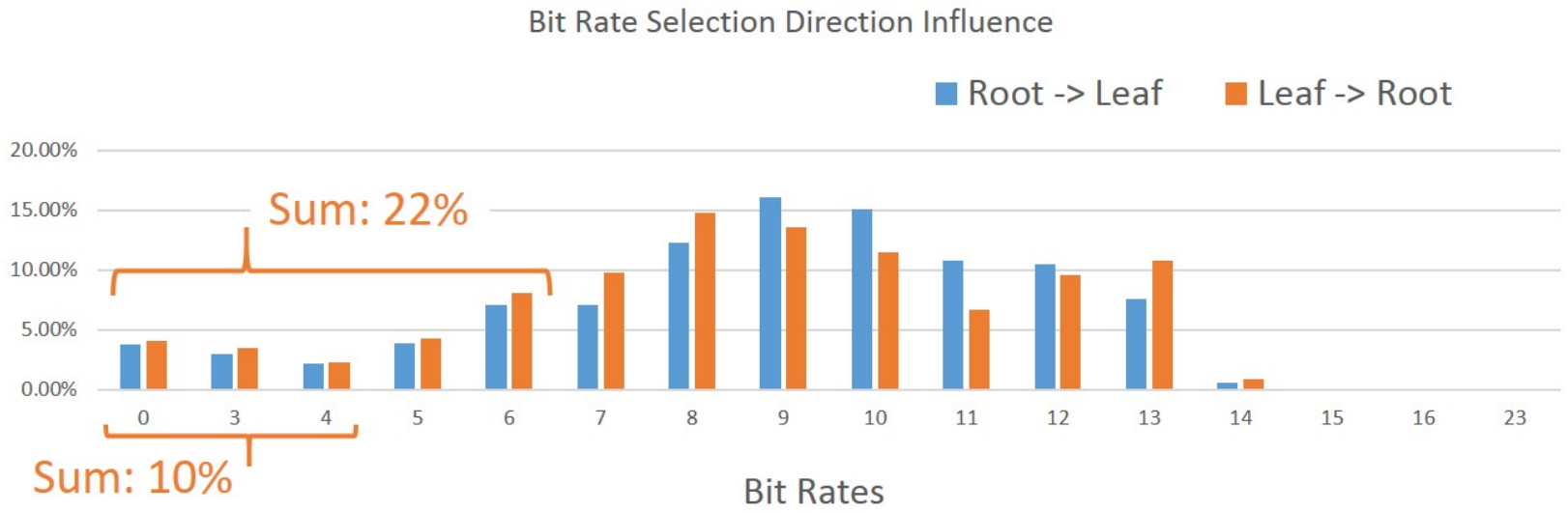
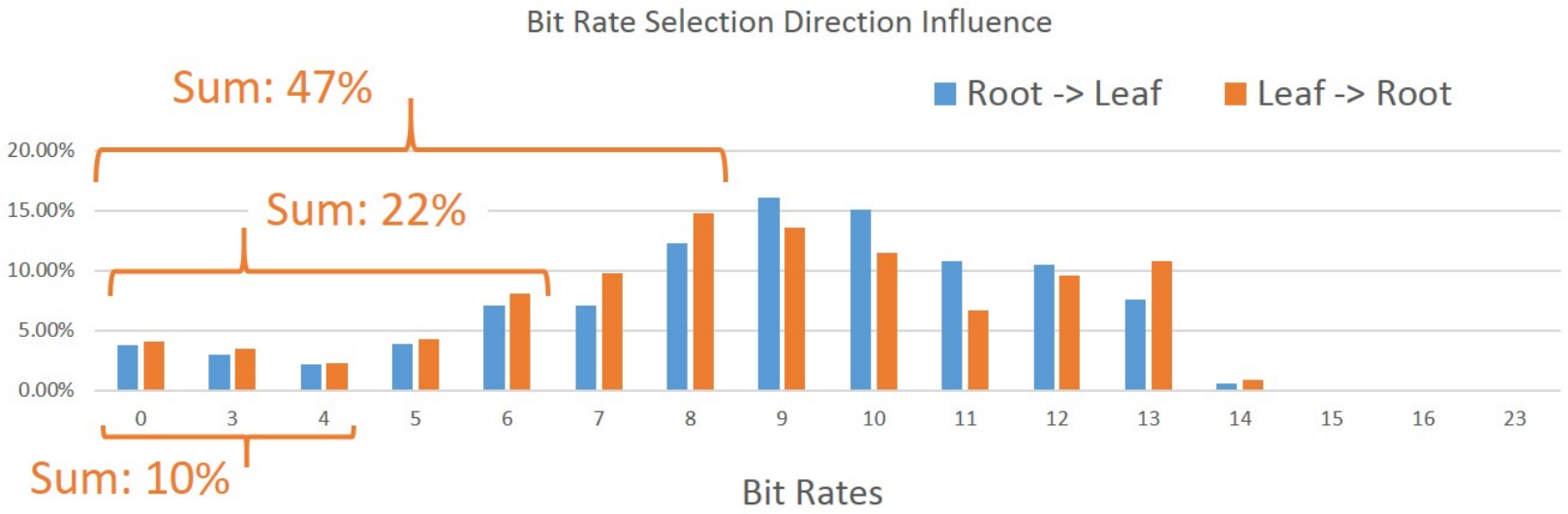
20.00%
15.00%
10.00%
5.00%
0.00%
0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
23
Sum: 10%
Bit Rates


Bit Rate Selection Direction Influence
Root -> Leaf
Leaf -> Root
20.00%
15.00%
10.00%
5.00%
0.00%
Sum: 22%
Sum: 10%
0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
23
Bit Rates


Bit Rate Selection Direction Influence
Root -> Leaf
Leaf -> Root
Sum: 47%
Sum: 22%
Sum: 10%
20.00%
15.00%
10.00%
5.00%
0.00%
0
3
4
5
6
7
8
9
10
11
12
13
14
15
16
23
Bit Rates

Some concrete examples

	Scramble	Idle	Walk	Cinematic
Num. key frames	24	80	38	2291
Num. animated tracks	56 (11%)	77 (15%)	82 (16%)	87 (16%)
Raw size	147 KB	489 KB	232 KB	14498 KB
Compressed size	7 KB	15 KB	12 KB	521 KB
Compression ratio	20 : 1	32 : 1	19 : 1	28 : 1
Avg key frame size	314 B	194 B	325 B	233 B
Decompression (XB1)	28us	32us	33us	27us

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Conclusion

- Sweet spot
  - Very fast decompression
  - Reasonably compact
  - High accuracy
  - Future proof

Conclusion

- Versatile
  - Works out of the box
  - Nothing to tweak
  - No need for fallback alternative

Conclusion

- Simple
  - Implemented in 20-25 days
  - No maintenance
  - Easy to build on and improve

Questions?

- **Blog:** http://nfrechette.github.io/