H-ETC2

Design of a CPU-GPU Hybrid ETC2 Encoder

PACIFIC GRAPHICS 2023
Daejeon, Korea

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INTRODUCTION

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- ▶ These days, high-quality textures are used to create computer graphics applications
  - games, movies…
- ▶ One example:
  - 5,000 4K X 4K-sized uncompressed textures = **83pixels**
- ▶ Using a lot of these high-quality textures
  → Require a lot of memory and bandwidth

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Paul Tassi Senior Contributor

News and opinion about video games, television, movies and the internet.

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(Photo: Bethesda Softworks)

(Source : Forbes)

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- One example:
  - 5,000 4K X 4K-sized uncompressed textures = **83pixels**
- Using a lot of these high-quality textures
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→ How to solve this problem?

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TEXTURE COMPRESSION

- Widely adopted for reducing the pressure on the memory and bandwidth
  - Lossy compression
- The texture is compressed and stored in memory before being passed to the GPU
  - Unpacked on the GPU in real time
- Reducing the footprint and bandwidth of texture memory
- Standard texture compression codec
  - Microsoft BC1-7 (Desktop)
  - ETC1/ETC2/EAC (Android)
  - PVRTC (iOS)
  - ASTC (Android/iOS)

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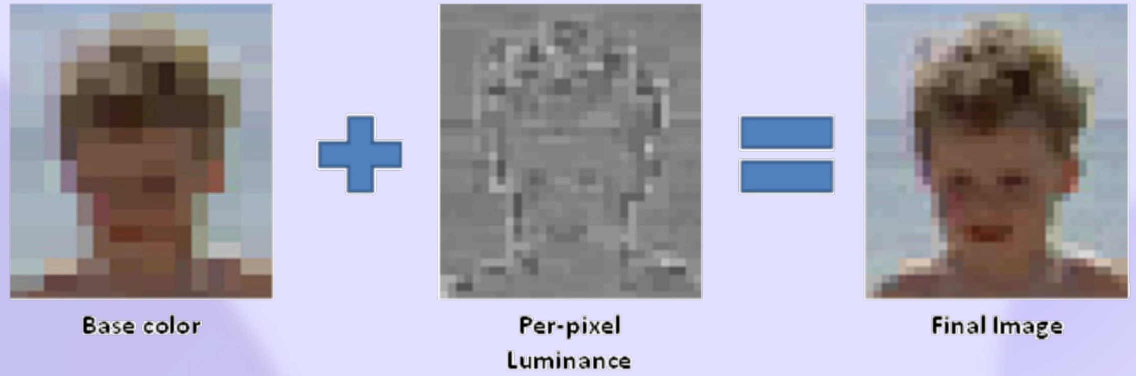
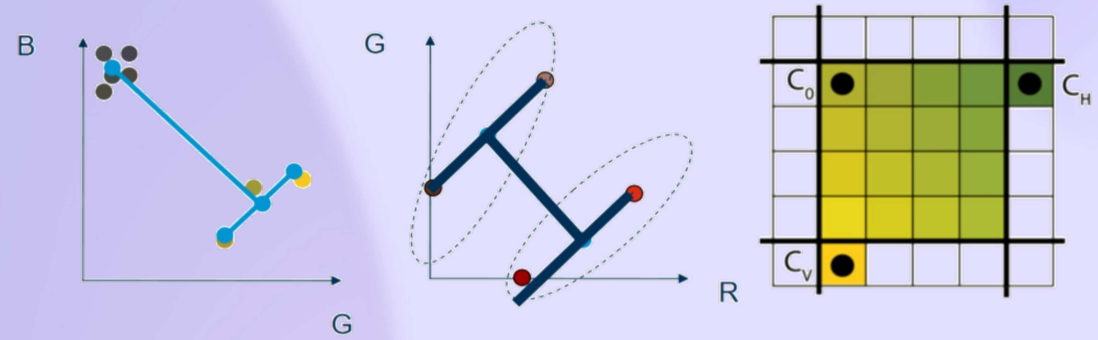
  - **ETC1/ETC2/EAC (Android)** **← This!**
  - PVRTC (iOS)
  - ASTC (Android/iOS)

ETC1/ETC2/EAC

- ETC1 (iPACKMAN)
  - OpenGL ES 2.0 standard
  - Two base chrominance colors + per-pixel luminance
  - 4x2 or 2x4 sub-blocks
  - 6 : 1 compression ratio

- ETC2
  - OpenGL ES 3.0 standard
  - Three additional modes : T, H & Planar
  - Less block & banding artifacts
  - Alpha support (EAC)





(a) T-mode (b) H-mode (c) Planar mode

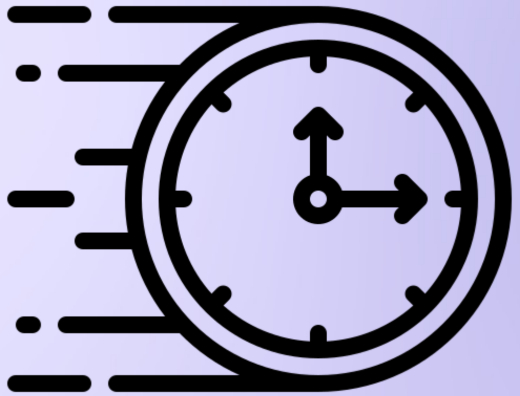
OUR OBSERVATION

- Our question

How can we achieve fast encoding speeds

While preserving as much quality as possible for artist-created textures?

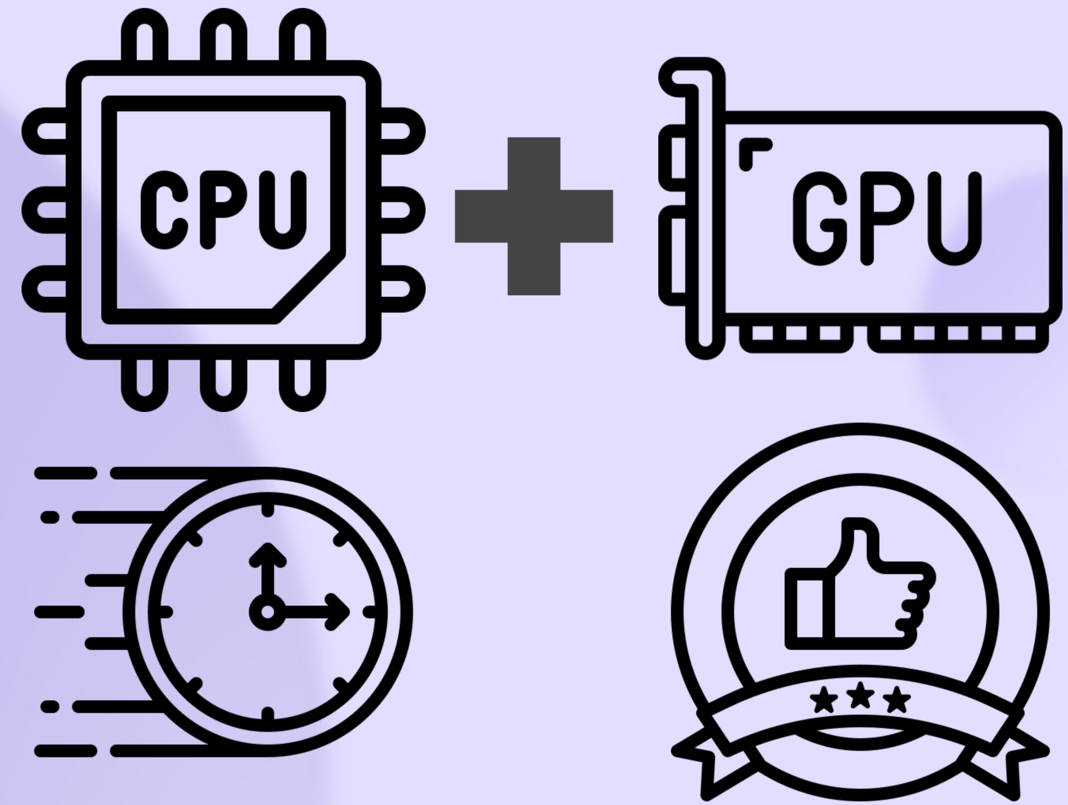
- We have to …
  - Better quality → more iterations & RGB space search
  - Faster encoding speed → light weight algorithm & optimization



OUR PROJECT : H-ETC2

- **GPU**
  - A Single Instruction Multiple Thread (SIMT) device

- We introduce a hybrid encoder using CPU-GPU,
  - which performs fast encoding with a CPU encoder and then improves the encoding with a GPU encoder



CORE RELATED ETC2 COMPRESSOR

QuickETC2
[Nah. SA2020]

- Ultra-fast multi-thread SIMD-optimized encoder
- Using two method
  - Early compression-mode decision
  - Luma-based T-/H-mode compression
- Integrated into
  - etcpak 1.0 encoder

Betsy
[Goldberge. 2022]

- Based on OpenGL open-source encoder
- Using improved encoding progress about each of modes
- Integrated into
  - Godot game engine

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Our CPU encoder

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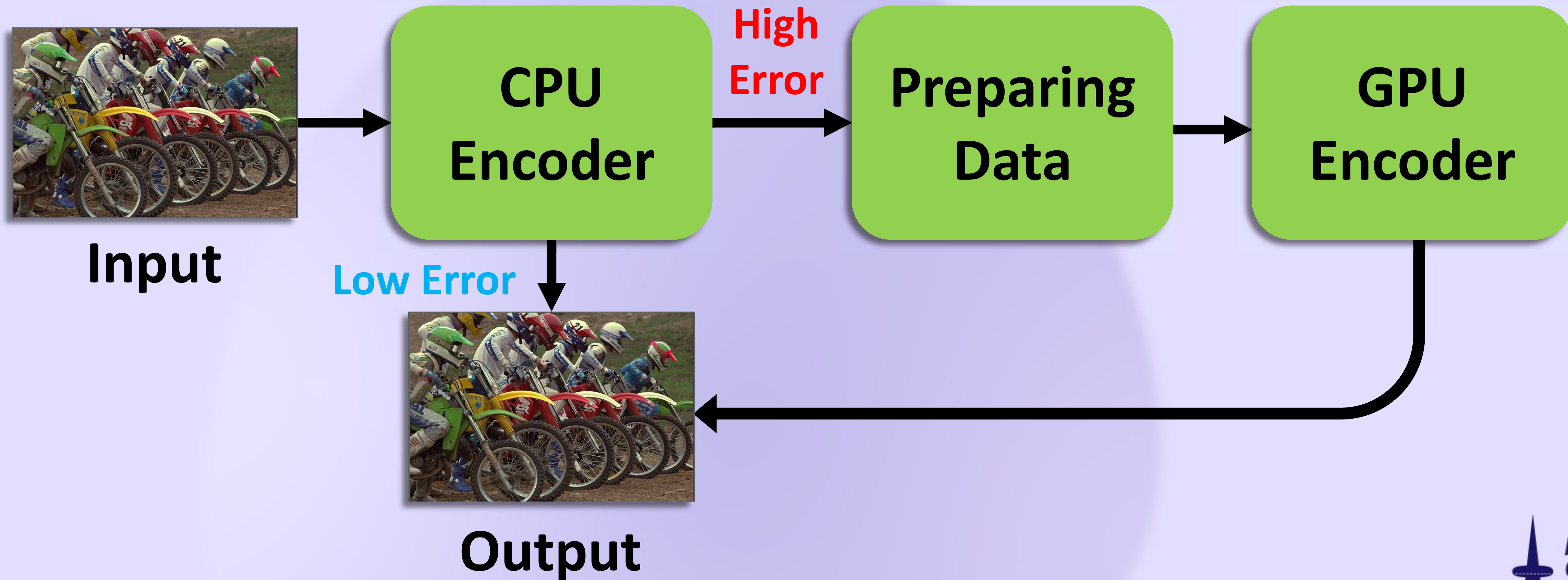
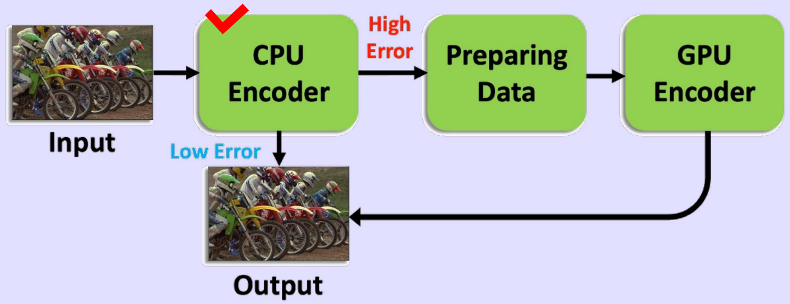
Our GPU encoder

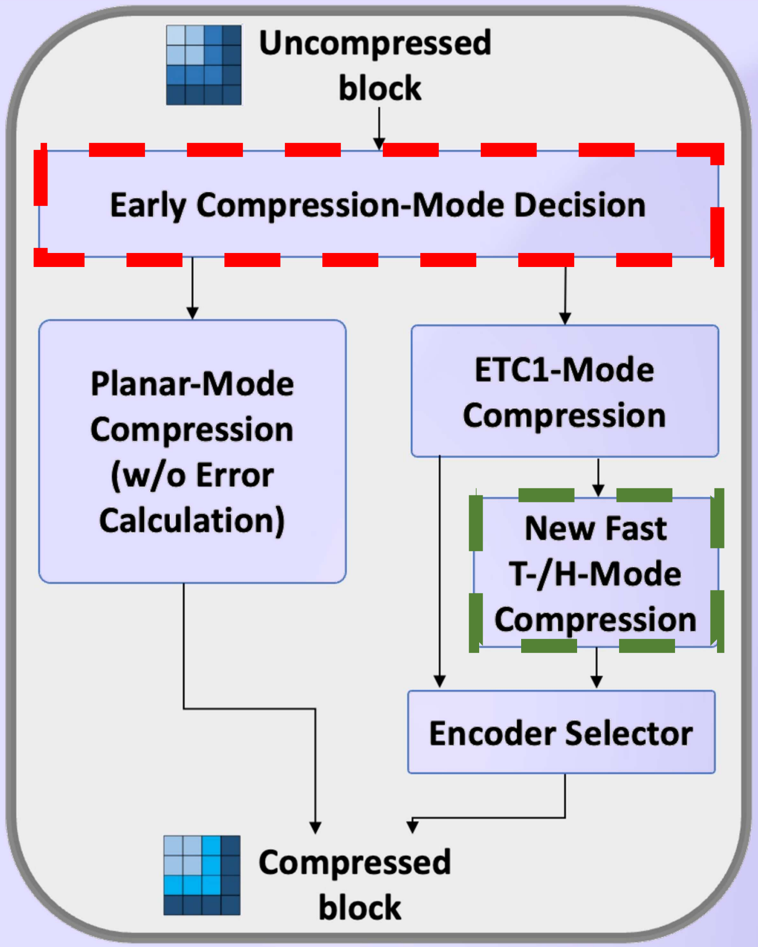
SYSTEM OVERVIEW

SYSTEM OVERVIEW



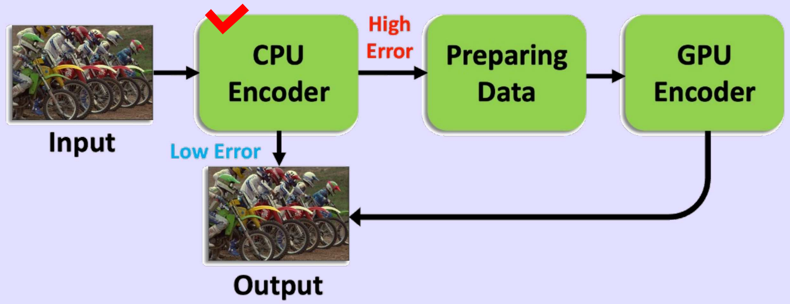
TRADITIONAL QUICKETC2

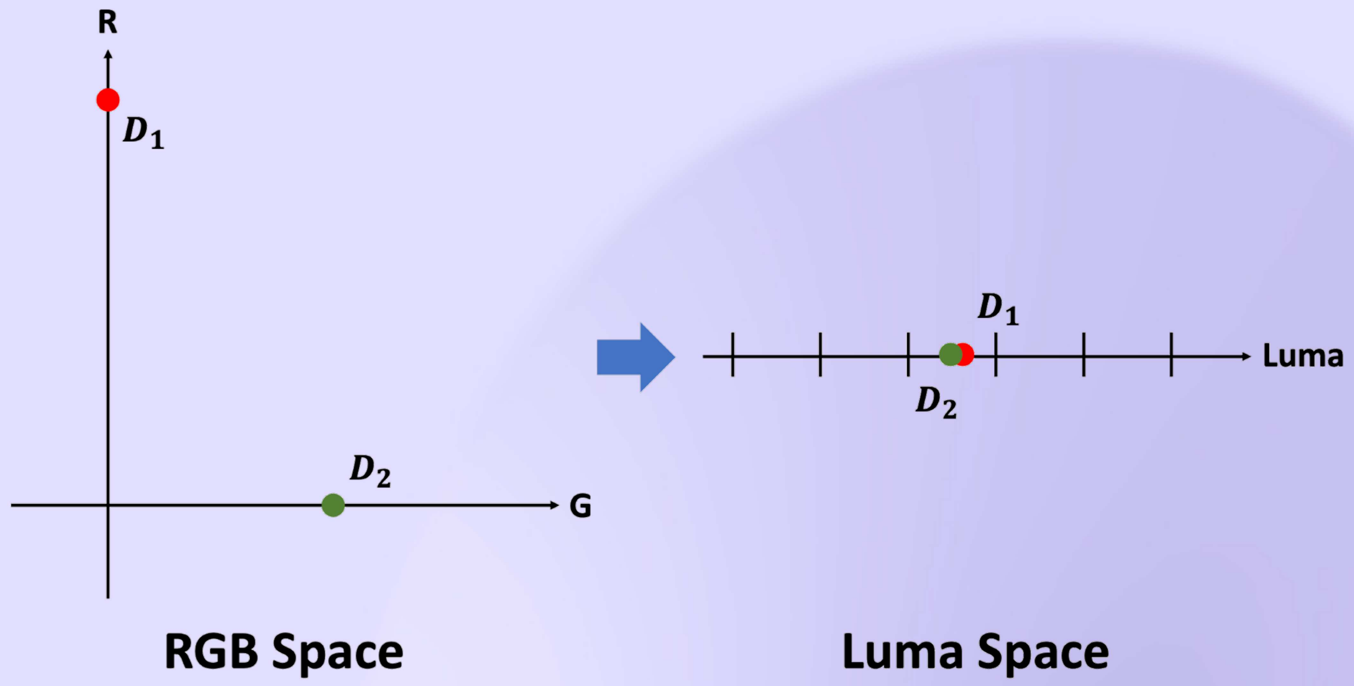




- ▶ **Early Compression-Mode Decision**
  - Block classification according to luma differences
  - Using luma differences to set the mode (ETC1, T-mode, H-mode, Planar-mode)
- ▶ **New Fast T-/H-Mode Compression**
  - Faster clustering by replacing the 3D RGB space with the 1D luma space
  - Reduction in the number of base-color pairs, compression modes & distance candidates
- ▶ **Fastest** encoding speed among ETC2 encoders

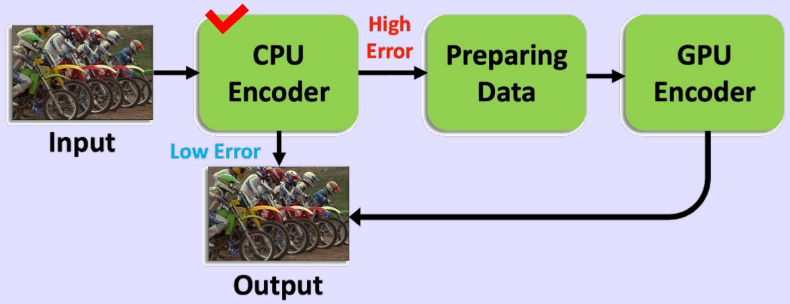
LUMA SPACE PROBLEM

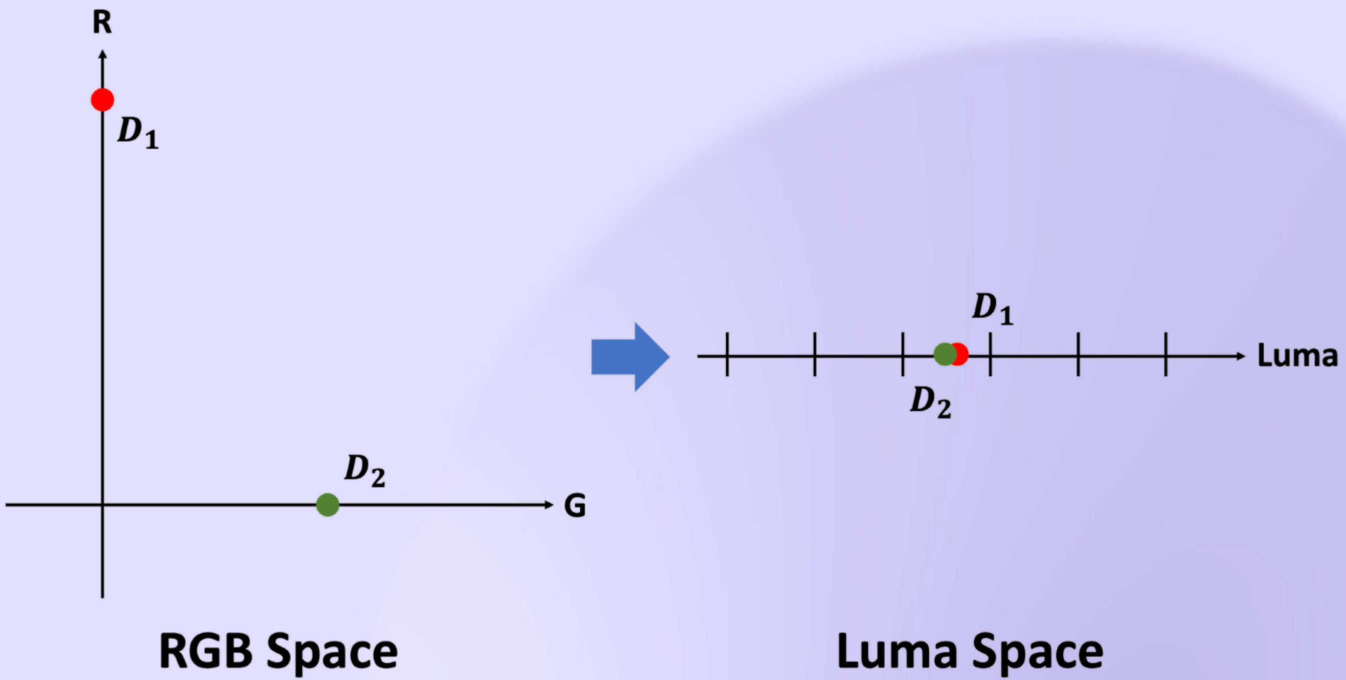




- Let's assume a situation
  - D_1 with RGB channel = (255, 0, 0)
  - D_2 with RGB channel = (0, 128, 9)
- $luma = 0.3 \times R + 0.59 \times G + 0.11 \times B$
- $D_{1(luma)} = 76.5, \quad D_{2(luma)} = 76.509$
- They become quite similar in the luma space
  → **probability of artifacts!**

LUMA SPACE PROBLEM



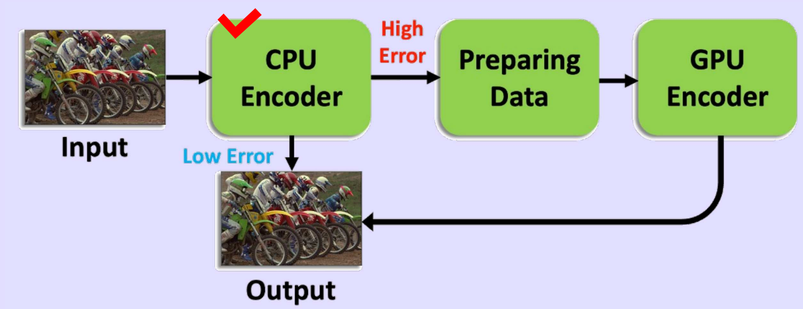


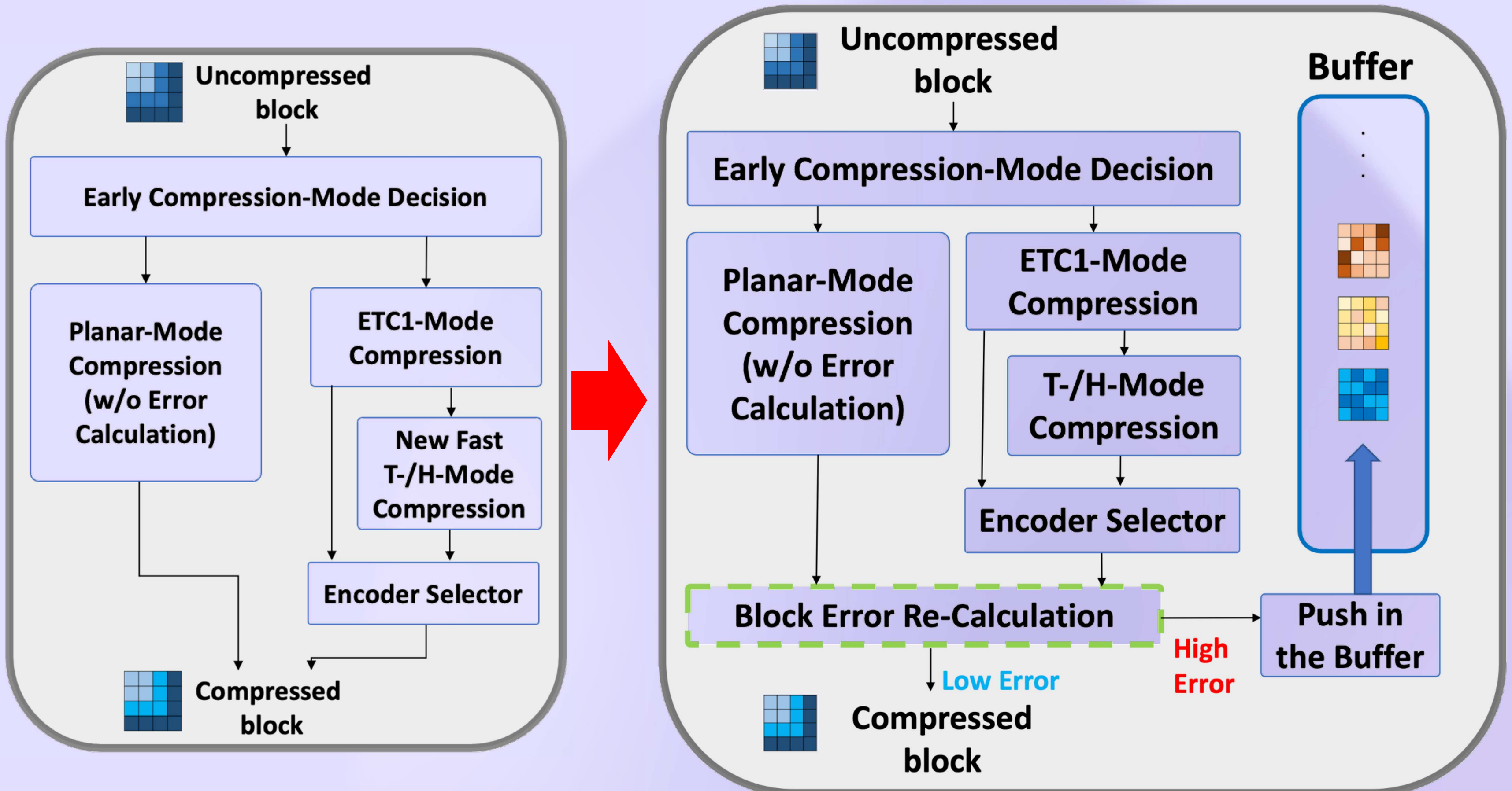
- ▶ Re-calculation error metric
  - To be conservative and check the errors of each channel
- ▶ if error > threshold T
  - it is determined as a problematic pixel block
  - The threshold value = ASTC encoder's "**dblimit**" (PSNR 35.68) [Smith. 2018]

$$error = \sum_{i=0}^{N-1} \max\left(\left|\bar{x}_{i,r} - x_{i,r}\right|, \left|\bar{x}_{i,g} - x_{i,g}\right|, \left|\bar{x}_{i,b} - x_{i,b}\right|\right)^2$$

$\bar{x}$: compressed pixel
x : original pixel

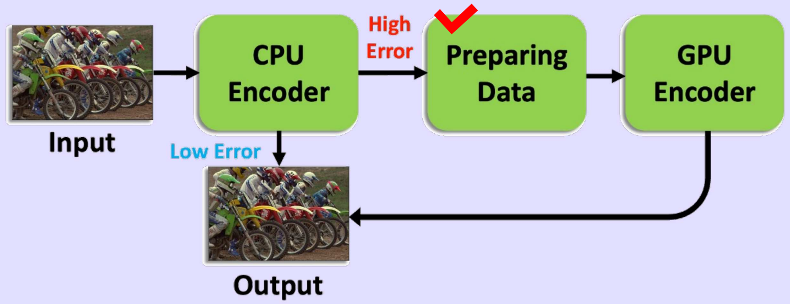
DESIGN OF THE CPU ENCODER

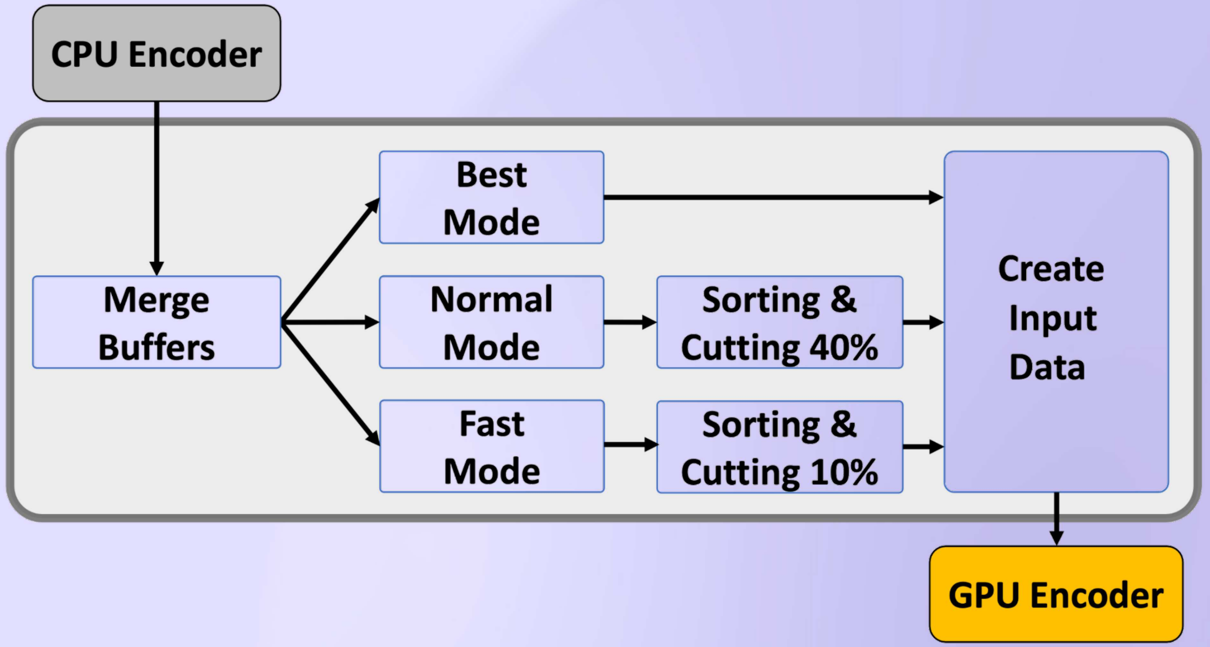




- Built upon QuickETC2 [Nah. SA2020] by adding the Block Error Re-Calculation
- Result → **high error?**
  - Save in the local buffer of thread
- Result → **low error?**
  - Directly, save in output

PREPARING DATA FOR THE GPU ENCODER





- We were inspired by Etc2comp [Google Inc. and Blue Shift Inc. 2017]

- A user can control the degree of quality
  - **Best mode**
    - No sorting, use **all** problematic pixel blocks
  - **Normal mode**
    - After sorting about errors, use only **40%** of all problematic pixel block
  - **Fast mode**
    - After sorting about errors, use only **10%** of all problematic pixel block

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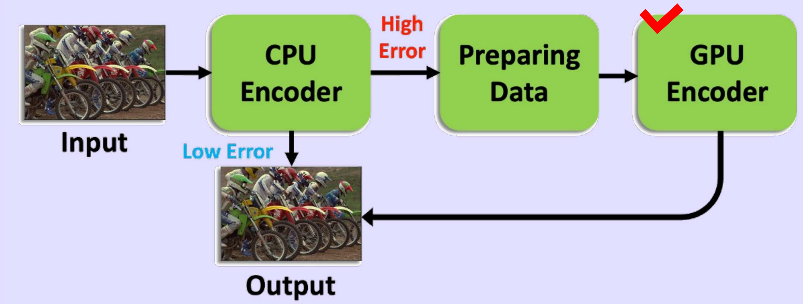
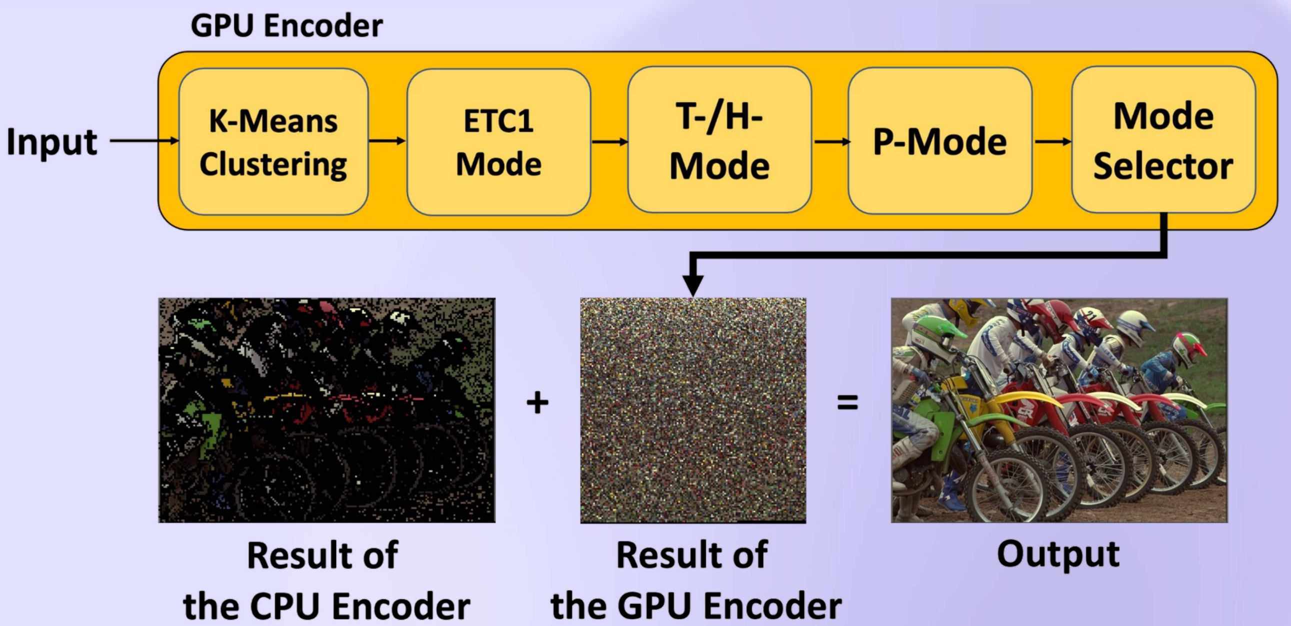
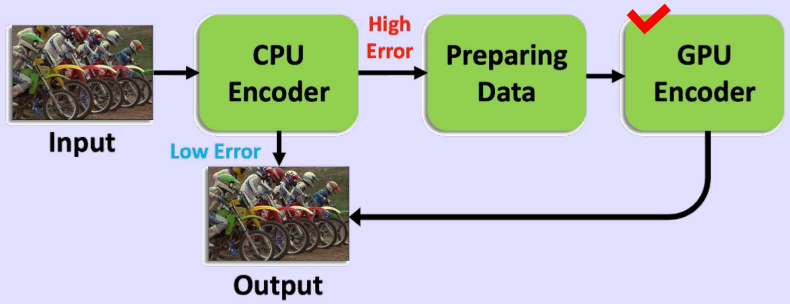
DESIGN OF THE GPU ENCODER

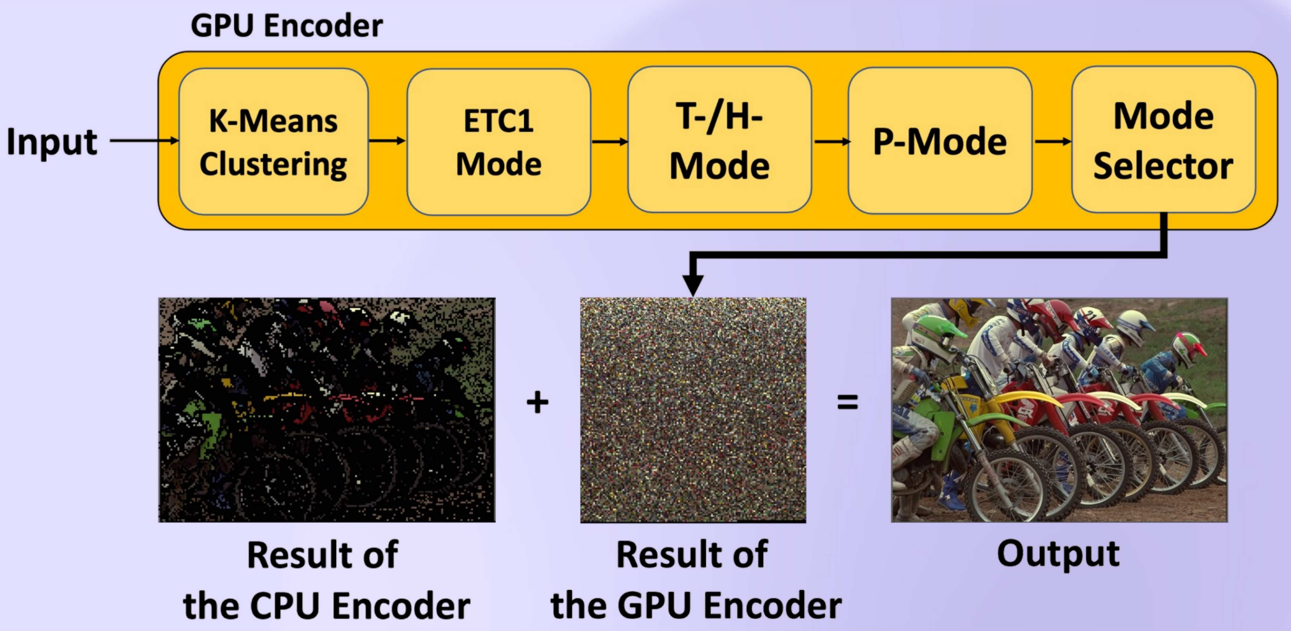




- Built upon Betsy [Goldberge. 2022]
- Two small changes that we did
  - Fixed quantization error
  - Applied perceptual error metric ($error = 0.3 \times R + 0.59 \times G + 0.11 \times B$)
- At the result, we could improve block artifacts

DESIGN OF THE GPU ENCODER





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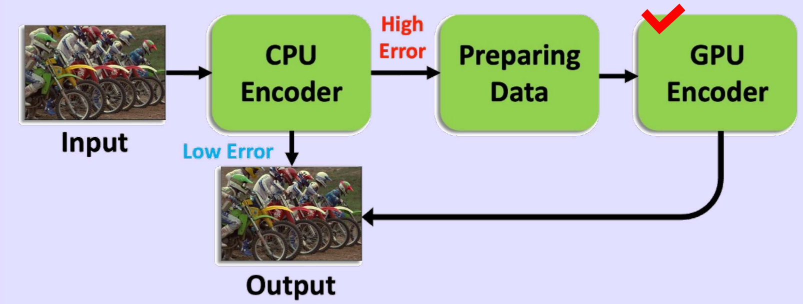
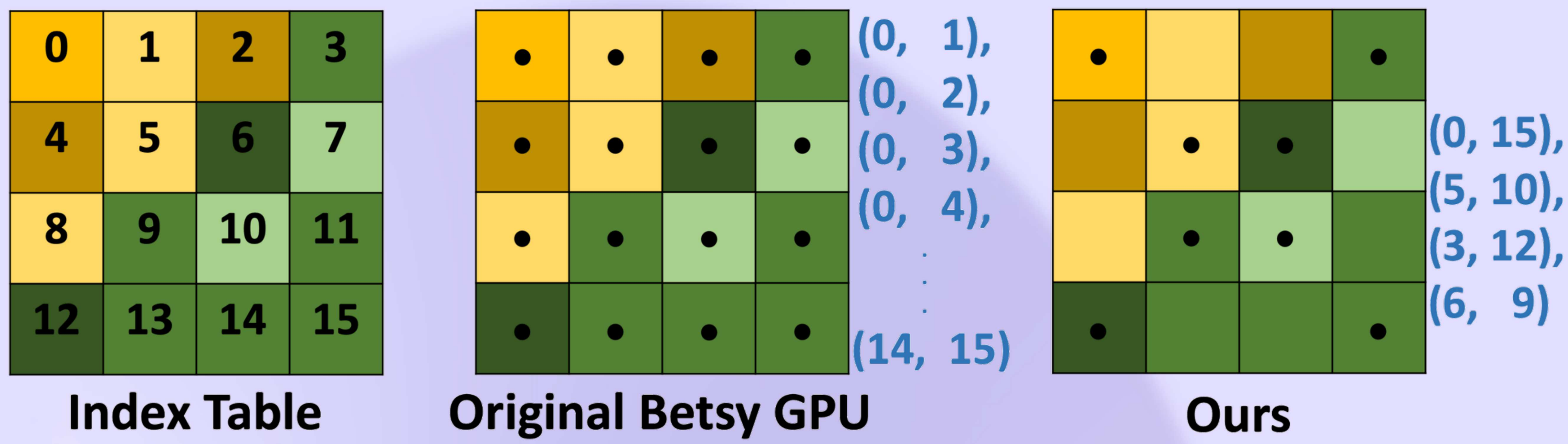
→ **However, this GPU version is much slower than the etcpak CPU encoder!**

SELECTIVE COMPRESSION METHOD

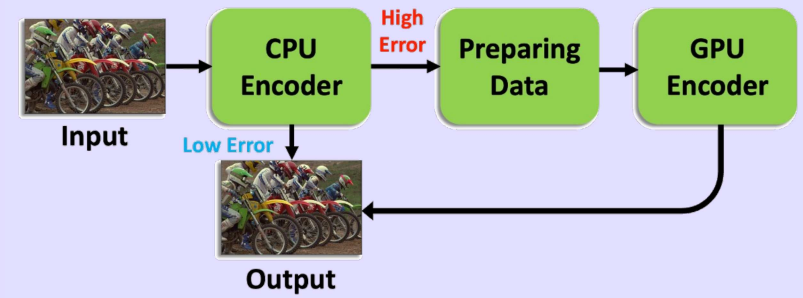




- ▶ The traditional T-/H-mode was studied to improve the diagonally part (edge)
- ▶ We were inspired selective compression method of THUMB [Pettersson et al. SL2005]

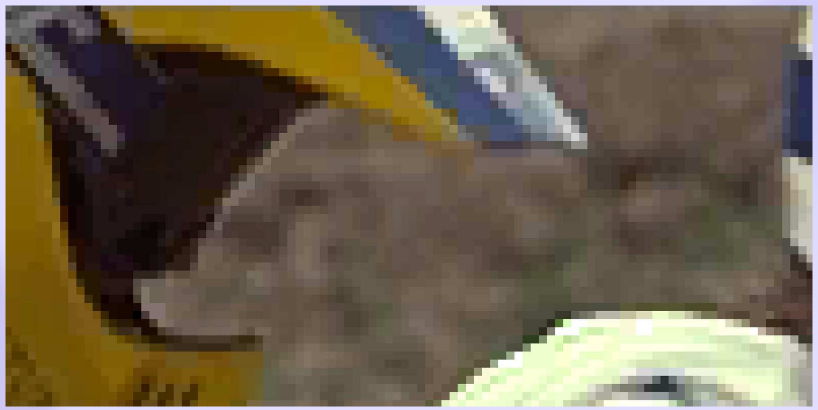
- ▶ Improved encoding speed by using fewer pairs of pixel candidates $({}_{16}C_2 = 120 \rightarrow 4)$
  - T-/H-mode handles diagonally divided clusters better than ETC1 mode
  - Pixels within each individual partition represent spatial consistency

EACH OF STEP IMPROVEMENT



Original
Betsy

+ Fix
quantization
errors



+ Apply
the perceptual
error metric

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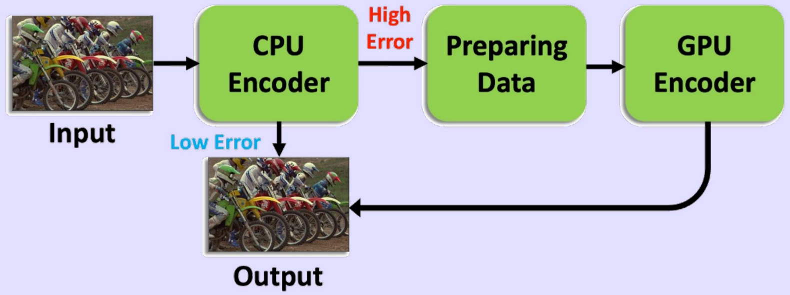
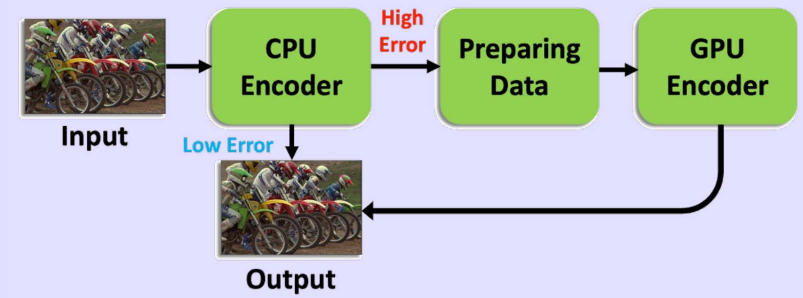


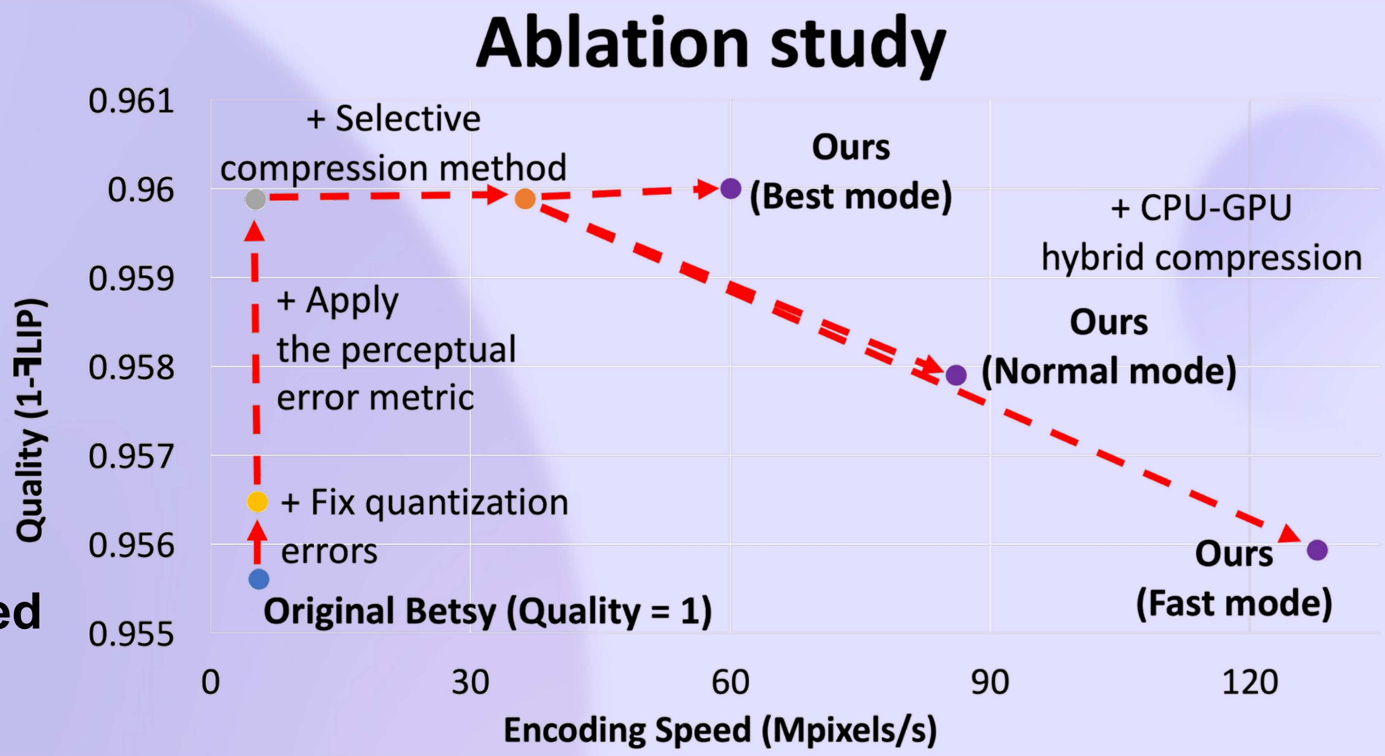
+ Selective compression method

+ CPU-GPU hybrid compression (Best mode)

Uncompressed

EACH OF STEP IMPROVEMENT





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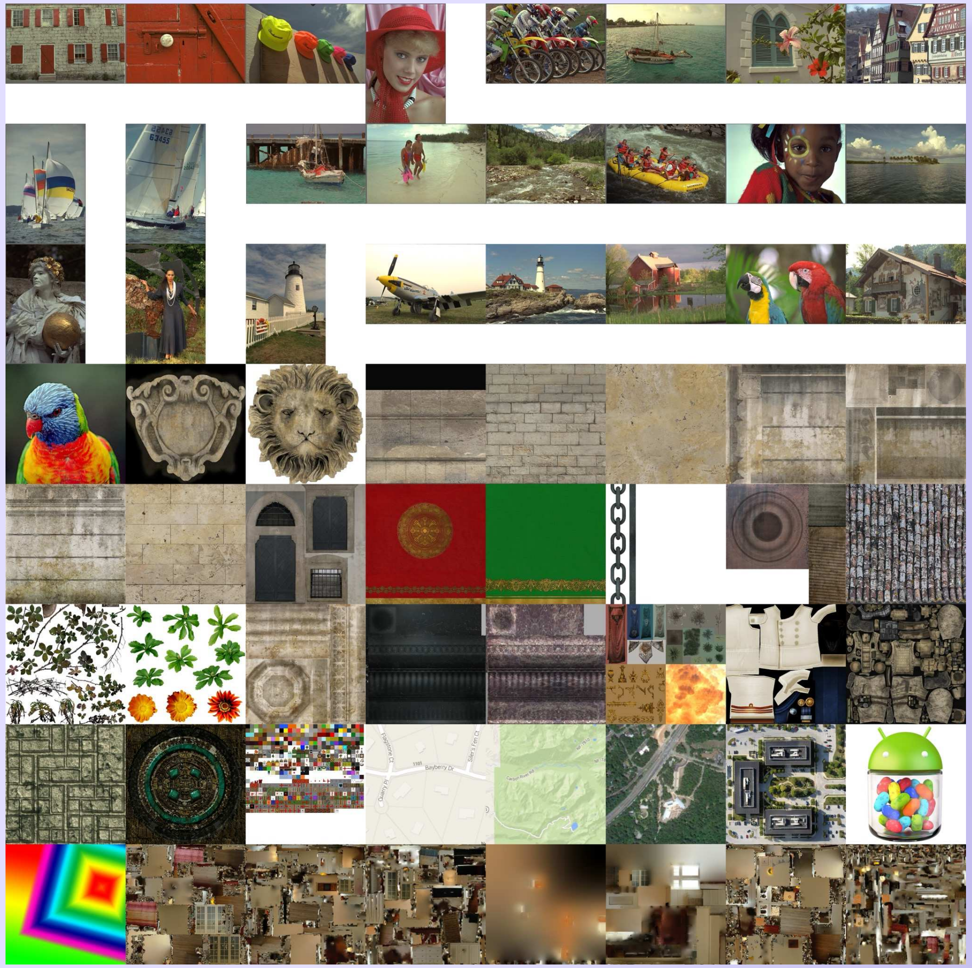
EXPERIMENT & RESULTS

TEST IMAGES



- 55 RGB + 9 RGBA texturers
- Size : 256 X 256 ~ 8192 X 8192

- **Photos** (No.1 – No.25)
  - Kodak Lossless True Color Image Suite & Lorikeet
- **Game textures** (No.26 – No.51)
  - Crytek Sponza, FasTC & Vokelia Spawn (Minecraft)
- **GIS maps** (NO.52 – No.55)
  - Google Maps & Cesium
- **Synthesized images** (No.56 – No.57)
  - Android Jelly & Gradient
- **Captured images for 3D reconstruction** (No.58 – No.64)
  - Bedroom

H/W & S/W SETUP

- Test environments
  - Intel Core i5-12400 CPU, 32GB of RAM, NVIDIA GeForce RTX 3060, a 1TB SSD

- Evaluation metric : ꟻLIP , Mpixels/s
  - Lower ꟻLIP value indicates good quality

- Compressor settings
  - etcpak 1.0 (QuickETC2)
  - Betsy with 0, 1, and 2 as the quality parameters
  - Etc2comp with the fast and best modes
  - ETCPACK with the fast and slow modes
  - H-ETC2 (our) with the fast, normal, and best modes

QUALITY & PERFORMANCE COMPARISON ON THE 64 TEST IMAGES

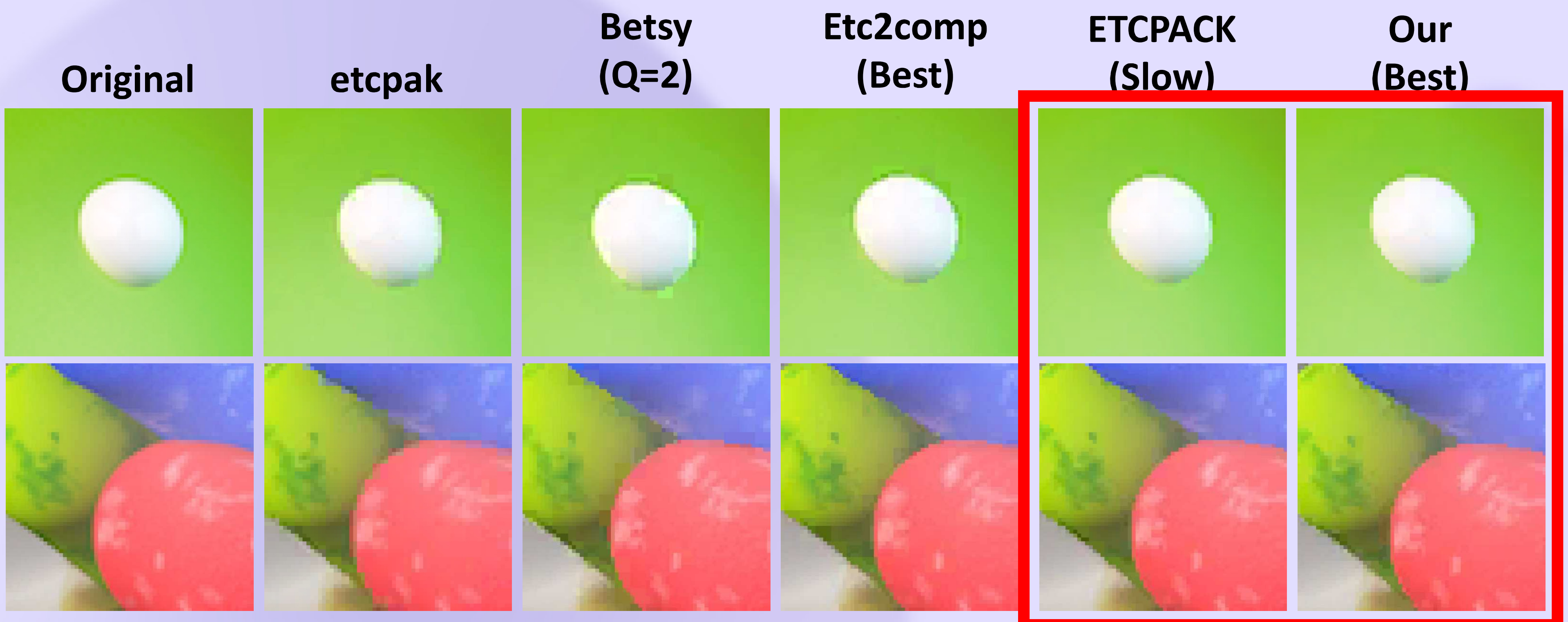
Compressor	Mode	ꟻLIP	Mpixels/s
etcpak		0.0506	1350.82
Betsy	Q=0	0.0474	6.20
	Q=1	0.0444	5.63
	Q=2	0.0438	2.22
Etc2Comp	Fast	0.0480	3.97
	Best	0.0419	0.15
ETCPACK	Fast	0.0419	0.85
	Slow	0.0375	0.0041
H-ETC2 (ours)	Fast	0.0440	127.87
	Normal	0.0421	86.15
	Best	0.0400	60.14

QUALITY & PERFORMANCE COMPARISON ON THE 64 TEST IMAGES

Jelly

QUALITY & PERFORMANCE COMPARISON ON THE 64 TEST IMAGES

Jelly



→ **Our (best) to ETCPACK (slow) show visually similar results**

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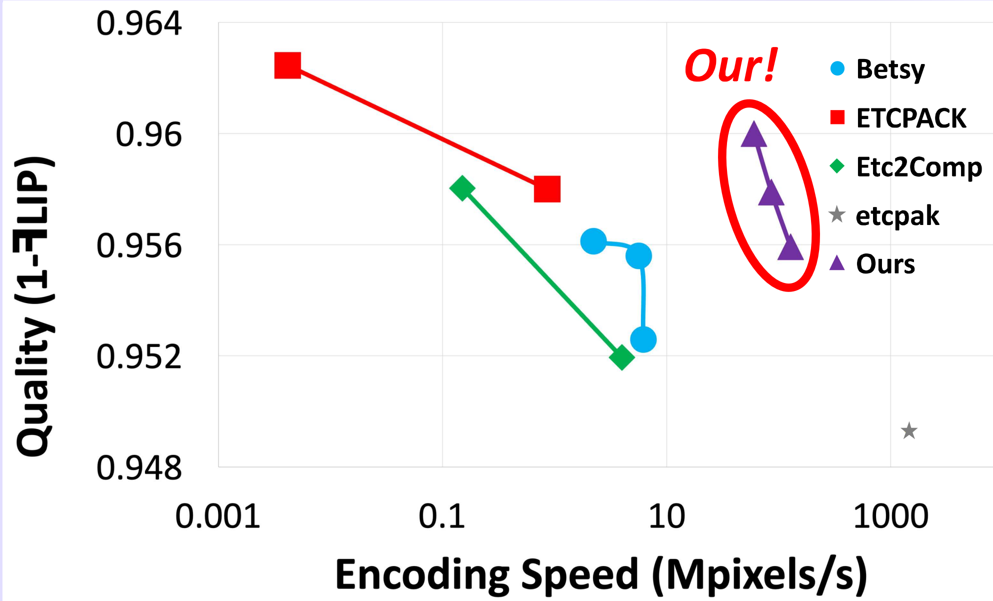

kodim23

Original | etcpak | Betsy (Q=2) | Etc2comp (Best) | ETCPACK (Slow) | Our (Best)

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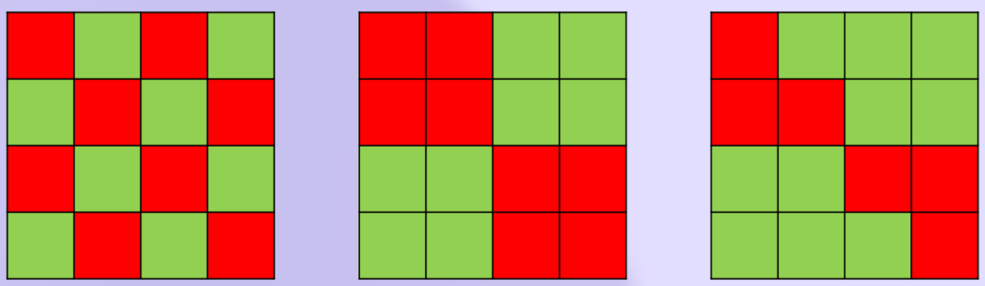
CONCLUDING REMARKS

CONCLUDING REMAKRS

- We have introduced a hybrid ETC2 encoding pipeline that combines CPU and GPU processing [H-ETC2 link]
  - As a result, our encoder achieves a better balance between compression quality and encoding speed

- Limitations
  - limitation about extreme pixel pattern



  - Still slower encoding speed of GPU encoder than CPU encoder

- Future works
  - We aim to explore the application of our CPU-GPU hybrid approach to other texture formats, including BC7 and ASTC
  - Enhancing performance by refining the balance between CPU and GPU processing times

THANK YOU!

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