SPAF: Sub-texel Precision Anisotropic Filtering

Hyun-Chul Shin and Lee-Sup Kim

Dept. of EE & CS
Korea Advanced Institute of Science and Technology
Taejon, Korea

Agenda

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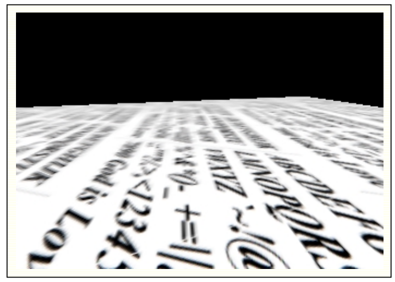
- ❑ Introduction
- ❑ Background and Previous Works
- ❑ Goals
- ❑ SPAF
  - ❖Algorithm
  - ❖H/W Cost Minimization
  - ❖Image Quality and H/W Cost Comparison
- ❑ Conclusions & Future Works

Introduction

Introduction

- Limitations with Tri-linear Filtering
  - Blurring
    - Severe artifacts in the rendered image
    - Due to approximation of footprint to square (Shape of footprint: Quadrilateral)
    - Box Filter



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Background

Background

- Anisotropic Filtering - reference to David B. Kirk (1998)
  - Adjust filtering to the **shape** of footprint, as well as **size**
  - **High Quality** vs. **More Texels and Computations**
  - Considerations
    - **LOD Selection**: Load More texels necessary for filter ing
    - **Shape**: Approximate the footprint shape Better
    - **Filter**: Need Good filter

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Previous Works (1)

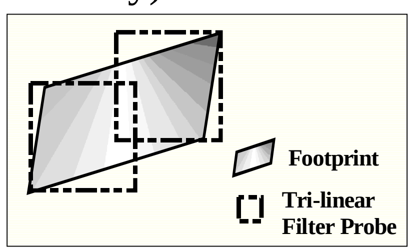
Previous Works

- ❑Two Approaches in Algorithm & H/W Architecture
  - ❖Assemble tri-linear filter probes
    - ➡TEXRAM(Footprint Assembly)
    - ➡Feline(Fast Elliptical Lines)
  - ❖Apply an area coverage weight to the texel
    - ➡Fast Footprint Mip-mapping

Previous Works (2)

Previous Works

- ❑TEXRAM(Footprint Assembly)
  - ❖Increase in Tri-linear Filter Probes
    - ➡Require **Many Texels**
  - ❖Box Filter



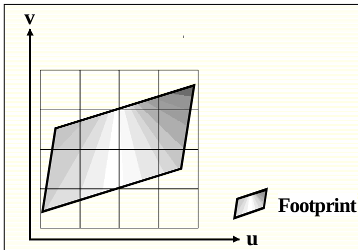
- ❑Feline(Fast Elliptical Lines)
  - ❖Accurate Calculation of Filter Probe Number
    - ➡**2 x** Number of Filter Probes in TEXRAM
  - ❖Gaussian Filter

Previous Works (3)

Previous Works

❑Fast Footprint Mip-mapping

- ❖LOD Selection using Aspect ratio of footprint
- ❖Area Coverage Weight
  - ➡with **Significant Quantization Error**
  - ➡**Large** Weight Table
- ❖Box Filter



$C_f = \sum_k C_k * W_k,$

With C_f : *filtered Color*,

C_k : *Texel Color*,

and W_k : *Area Coverage Weight*

Goals

Goals

❑To Provide

- ❖SPAF Algorithm
  - ➡Filtering algorithm under limited number of texels(*M*)
  - ➡with LOD Selection Using Aspect Ratio of Footprint
  - ➡with **Sub-texel Precision Area Coverage Weight**
  - ➡using Gaussian Filter
- ❖ H/W Cost Minimization
  - ➡Sub-texel Precision Area Coverage Weight Table Min imization

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Characteristics of Edge Function

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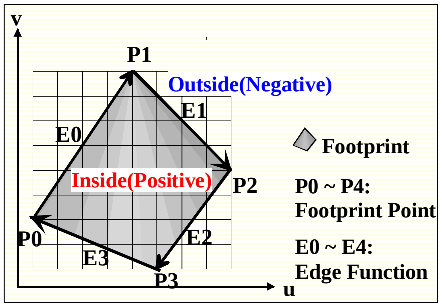
- ❑ Footprint is represented by Four Edge Functions
- ❑ Edge Function
  - based on Andreas Schilling (1991)
  - ❖ Sign of Edge Function
    - ➡ Inside or Outside
  - ❖ Absolute value of Edge Function
    - ➡ Manhattan distance between an edge and a point



Area Coverage of Texel

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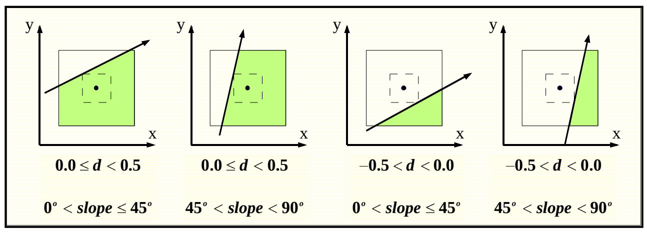
❖ *A = f(slope, d), with A: Area Coverage,*
slope: Slope of Edge,
and d: Value of Edge function

➡ ***d*** < -0.5: **No** area coverage

➡ ***d*** > +0.5: **Full** area coverage

➡ -0.5 < ***d*** < +0.5: **Partial** area coverage
: ***slope*** determines the **shape and size** of partial area coverage



Sub-texel Precision Area Coverage Generation

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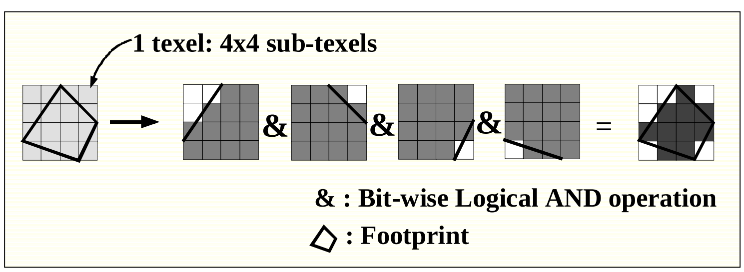
❑ Intersection of four sub-texel masks of the footprint



❖ Sub-texel mask table size: 4KBytes

➡ 2^5(edge slope) x 2^6(edge function) x 2^4bits(4x4 sub-texel mask)

❖ Sub-texel mask table size ***per* texel**: **16KBytes**

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Gaussian Filter

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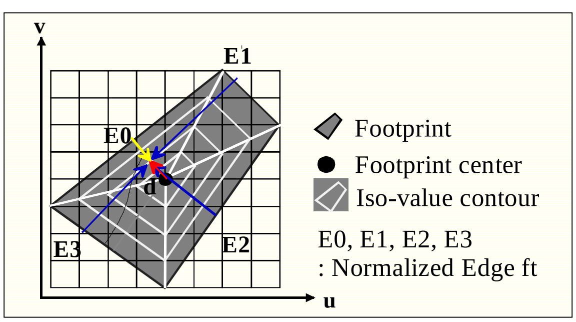
- ❑ $W_G = exp(-a*d^2)$,
  With a: filter coefficients,
  d: Normalized distance from the center to the texel
- ❑ Relation Equation: ***1 = d + E***
  - ❖ ***E*** = min{E0, E1, E2, E3}



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    - ➡<u>Area Coverage ROM Minimization</u>
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H/W Architecture

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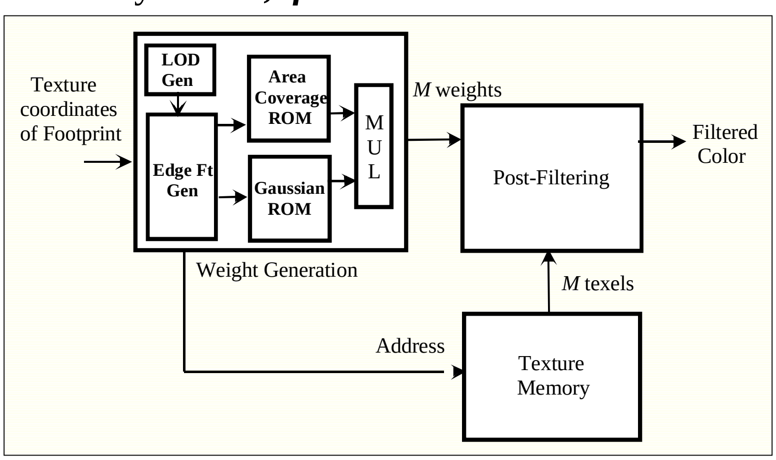
- ❑ Area Coverage ROM size
  : 16KBytes x ***M***, ***for M texels***



Observations On Sub-Texel Mask

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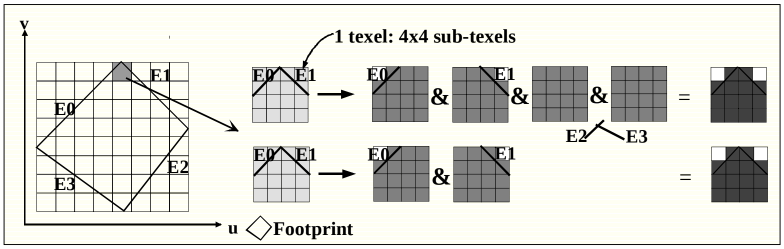
❖ **Observations I**

➡**Fully Covered Sub-texel Mask** has **No Effect** on **Partial Area Coverage** Generation



❖ **Observations II**

➡The number of texels which **four or three** edges cross is ***FEW***

➡In **Most** texels, edges **Less than three** cross

Texel Type Classification

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❑ **Texel Type Definition**

❖ *Type IV*: Texel which four or three edges cross

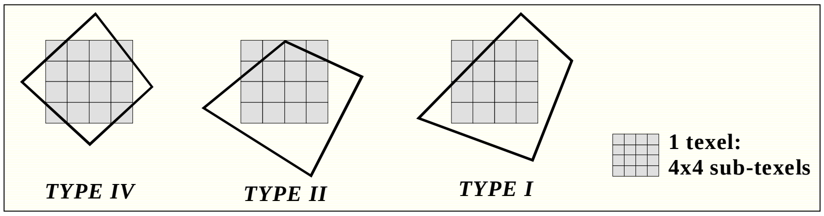
➡Four sub-texel mask ROMs (16KBytes)

❖ *Type II*: Texel which two edges cross

➡Two sub-texel mask ROMs (8KBytes)

❖ *Type I*: Texel which one edge crosses or no edges cross

➡One area coverage ROM (1KBytes)



Number of Texel Type

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❖ Simulation Results used to Obtain Number of Texel Type

		Max. Num. of Occurrence	Three Simulation Cases
M : 16	Case I	6	**Case I :** **Occurrence of Only *Type IV***
	Case II	12	
	Case III	16	
M : 32	Case I	6	**Case II :** **Occurrence of Both *Type IV* and *Type II (i.e. Type IV+ Type II)***
	Case II	24	
	Case III	32	
M : 64	Case I	6	**Case III :** **Occurrence of All Types**
	Case II	32	
	Case III	64	

❖ **Number of each Texel Type is given as**

- ➡***Type IV*** : Case I
- ➡***Type II*** : Case II – { *Type IV* i.e. Case I }
- ➡***Type I*** : Case III – { (*Type IV* + *Type II*) i.e. Case II }
- ➡***Ex) At M* = 16, *Type IV* = 6, *Type II* = 6, and *Type I* = 4**

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    - ➡Image Quality Comparison
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Quality of Image

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- SNR(Signal to Noise Ratio)
  - T_{image}: test image, R_{image}: reference image

$$10\log_{10}\frac{\sum_{i,j} T_{image}(i,j)^2}{\sum_{i,j}\left[T_{image}(i,j)-R_{image}(i,j)\right]^2}\ (dB)$$

- Simulation Condition
  - Texture: **Checkerboard and text** with 256x256 resolution
  - Image resolution: 640x480
  - **Reference image**: **Elliptical Weighted Average(EWA)**
  - Test image: Feline,
    TEXRAM,
    FFM(Fast Footprint Mip-mapping),
    and SPAF(Sub-texel Precision Anisotropic Filtering)

Image Quality Comparison

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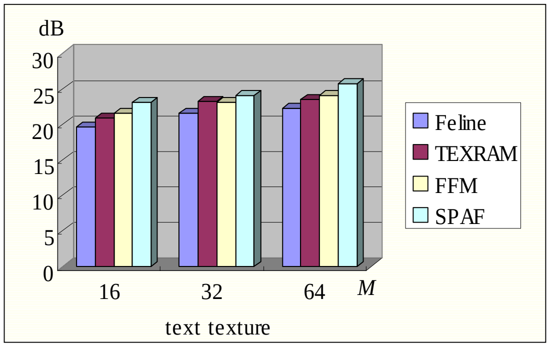
- Simulation Results & Comparison
  - Feline achieves **Lowest SNR**
  - At M = 32 or 64, TEXRAM **rivals** FFM
  - At M = 16, FFM achieves **Higher SNR** than TEXRAM
  - SPAF achieves **Highest SNR**



Test Scene

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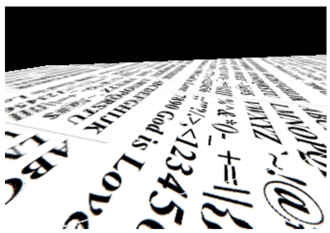
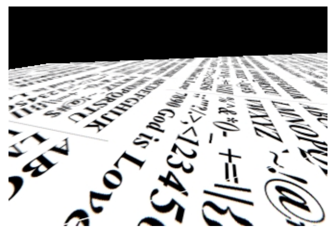
❖ Test scenes with text font texture at $M = 16$

Feline

TEXRAM



Fast footprint mip-mapping



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H/W Cost Comparison

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❖Area coverage table size at M = 16 ~ 64

ROM Size Based On Texel Type

	TYPE IV (16KB)	*TYPE II* (8KB)	*TYPE I* (1KB)	Total Size
M : 16	6	6	4	148KBytes
M : 32	6	18	8	248KBytes
M : 64	6	26	32	336KBytes

ROM Size Comparison of Two Algorithms

	Fast footprint mip-mapping	SPAF (Non-Minimization)	Ratio	SPAF (Minimization)	Ratio
M : 16	286K x 2 = 572KBytes	16K x 16 = 256KBytes	2 : 1	148KBytes	4 : 1
M : 32	3.5M x 2 = 7MBytes	16K x 32 = 512KBytes	14 : 1	248KBytes	28 : 1
M : 64	6.6M x 2 = 13.2MBytes	16K x 64 = 1024KBytes	13 : 1	336KBytes	40 : 1

➡1/2(4) ~ 1/13(40) of fast footprint mip-mapping

Conclusions & Future works

Conclusions

❑Proposed Key Schemes

❖Filtering algorithm using the sub-texel precision area coverage and Gaussian filter weight

❖Area coverage ROM minimization based on texel types

❑Proposed Algorithm & Architecture achieves

❖Quality of image **Superior to** other algorithms at the **Same** loaded number of texels

❖H/W cost **Smaller** than fast footprint mip-mapping So, **Amenable** to H/W implementation

❑Future Works

❖Texture Cache & Effective filtering at the Magnification