Gather - Scatter

Tran Giang Son, tran-giang.son@usth.edu.vn

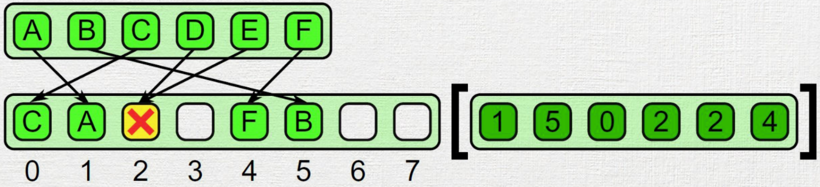
ICT Department, USTH

Scatter

What?

- “Sequential read, scattered random write”
- A relationship *from input* to output
- Smaller set of values is distributed (**written**) into another array
    - [Optional] with an index vector
- There may be gaps in the output array
- Highly memory intensive

What?



Why?

- Efficient memory access
  - Pre-cache contents
- Array of Struct (AoS) to Struct of Array (SoA)
- Building block of other algorithms
  - e.g. Radix sort

How?

- In below examples, `lookup` is a lookup index table
- In serial fashion

```
for i in range(N):
    dst[lookup[i]] = src[i]
```

- In parallel

```
tidx = ...
dst[lookup[tidx]] = src[tidx]
```

Examples

- RGB to HSL

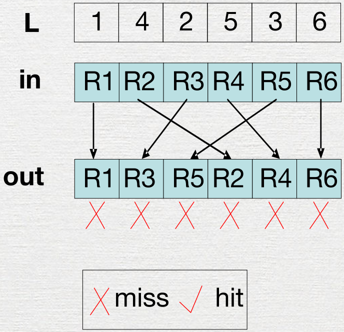
```
outH[tid] = h
outS[tid] = s
outL[tid] = l
```

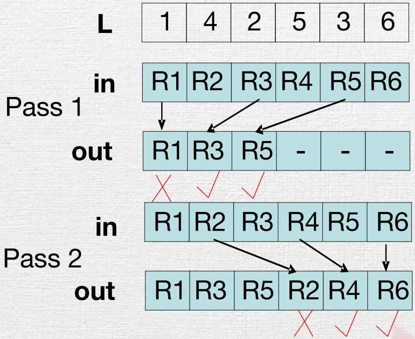
Optimization

- Exploit cache locality
- Multi-pass scatter [1]
  - n passes
  - Divide output to n areas
  - In i^{th} pass
    - Check destination
    - Write only if in i^{th} area

[1] Efficient Gather and Scatter Operations on Graphics Processors

Optimization





Labwork 8: Scatter

- To prepare for the next "Gather" labwork, we need to convert the input image:
  - From RGB to HSV, from AoS to SoA: to 3 different arrays (`H[]`, `S[]`, `V[]`)
  - Reversely, from HSV to RGB, from SoA to AoS
- Implement the two scatter 2D kernels `RGB2HSV()` and `HSV2RGB()`
- Test the two kernels for a sample image (convert to HSV and convert back to RGB), compare the output with the input image
- Write a report (in LaTeX)
  - Name it « Report.8.scatter.tex »
  - Explain how you implement the labworks

Extra: HSV

- Hue, Saturation, Value
  - $H \in [0..360]$: “The color”. Red? Yellow? Cyan? Magenta?
  - $S \in [0..1]$: “The colorfulness”. Really cyan? Light yellow?
  - $V \in [0..1]$: “The brightness”. Dark cyan? Crimson?

Extra: RGB to HSV

- Preparation
  - Scale R, G, B to [0..255] to [0..1]
  - Find max and min among $R, G, B \in [0..1]$
  - $\Delta = max - min$
- Conversion

$$H = \begin{cases} 0^o & \Delta = 0 \\ 60^o \times (\frac{G-B}{\Delta} \bmod 6) & max = R \\ 60^o \times (\frac{B-R}{\Delta} + 2) & max = G \\ 60^o \times (\frac{R-G}{\Delta} + 4) & max = B \end{cases}$$

$$S = \begin{cases} 0 & max = 0 \\ \frac{\Delta}{max} & max \neq 0 \end{cases}$$

$$V = max$$

Extra: HSV to RGB

- Preparation

- $d = H/60$
- $hi = (int)d \bmod 6$
- $f = d - hi$
- $l = V \times (1 - S)$
- $m = V \times (1 - f \times S)$
- $n = V \times (1 - (1 - f) \times S)$

- Conversion

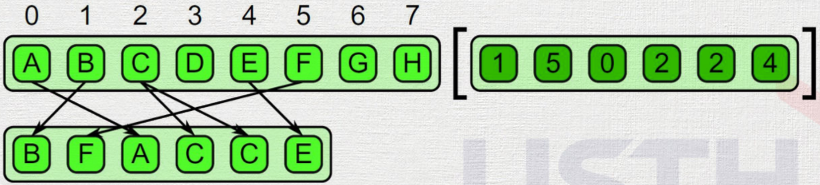
$$(R, G, B) = \begin{cases} (V, n, l) & 0^o \le H < 60^o \\ (m, V, l) & 60^o \le H < 120^o \\ (l, V, n) & 120^o \le H < 180^o \\ (l, m, V) & 180^o \le H < 240^o \\ (n, l, V) & 240^o \le H < 300^o \\ (V, l, m) & 300^o \le H < 360^o \end{cases}$$

- Scale R, G, B from $[0..1]$ to $[0..255]$

Gather

What?

- "Gathered random read, sequential write"
- A relationship *from output* to input
- Large set of values are **read** from an array
  - [Optional] with an index vector
- No gap in the output array
- Highly memory intensive



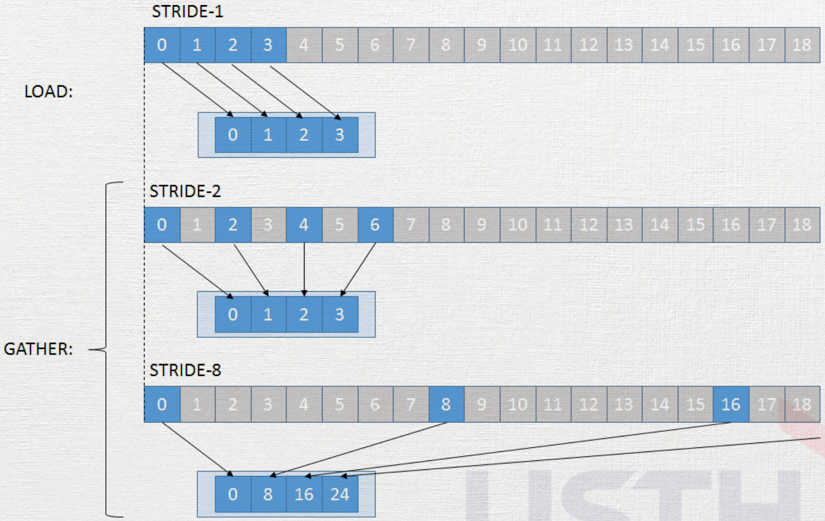
Why?

- Struct of Array (SoA) to Array of Struct (AoS)
  - Efficient memory access
- Building block of other algorithms
  - e.g. Radix sort

Why?

- Strided memory access
    - Memory fields accessed are equally distant
    - Called a stride
- Gathered ⇒ contiguous access

Why?


STRIDE-1
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
LOAD:
0 1 2 3
STRIDE-2
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
0 1 2 3
GATHER:
STRIDE-8
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
0 8 16 24

How?

- In below examples `lookup` is a lookup index table
- In serial fashion

```
for i in range(N):
    dst[i] = src[lookup[i]]
```

- In parallel

```
tid = ...
dst[tid] = src[lookup[tid]]
```

Example

- Horizontally flipping image

```
dst[tidy][tidx][0] = src[tidy][w - tidx][0]
dst[tidy][tidx][1] = src[tidy][w - tidx][1]
dst[tidy][tidx][2] = src[tidy][w - tidx][2]
```

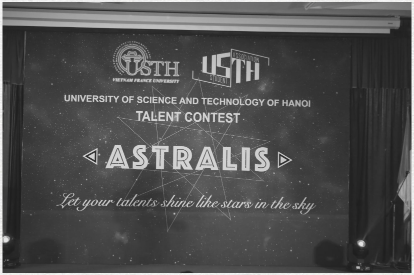
Labwork 9: Histogram Equalization

- Implement labwork 9a: Histogram
  - Calculate histogram of input **grayscale** image
- Implement labwork 9b: Histogram Equalization for **grayscale** image
  - Equalize the histogram for that input image
- Write a report (in $\LaTeX$)
  - Name it « Report.9.gather.tex »
  - Explain how you implement the labworks
  - Explain and measure speedup, if you have performance optimizations
- Push the report and your code to your forked repository

Extra 9a: Histogram

- Graphical representation of the value distribution in a digital image
  - Divide range of values to certain ranges (“bins”)
  - Count number of value occurences for each “bin”
- For image: an array, each element i in the array counts the number of pixels having gray level i

Extra 9a: Histogram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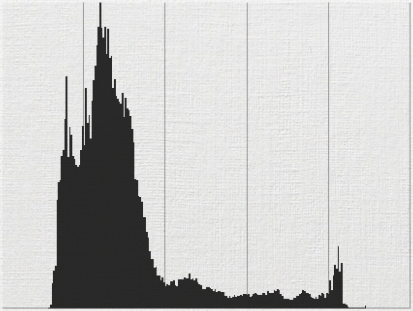

Extra 9a: Histogram

In serial

```
for y in range(height):
    for x in range(width):
        histo[input[y][x]]++
```

Extra 9a: Histogram

In parallel: 2 ways

- Atomic operations
  - Race condition due to parallelization
  - Not discussed this week. Next week with Prof. Lillian Aveneau.
- Local histogram
  - Each thread calculates a local histogram `lhisto[]` of a region in image (GATHER)
  - A sum is then combined for all regions (REDUCTION)

Extra 9b: Histogram Equalization

- Previously, grayscale stretch (LW 7)
    - Increases global contrast
    - Linearly calculates intensity of each pixel from $[min..max]$ to $[0..255]$
- Histogram equalization
    - Increases global contrast
    - Recalculates intensity using normalization of cumulative distribution function

Extra 9b: Histogram Equalization

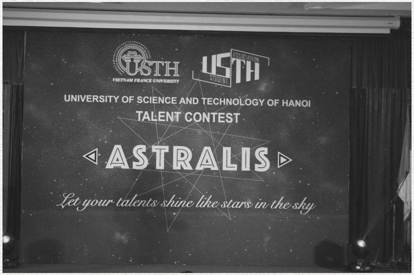
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Figure 1: Original

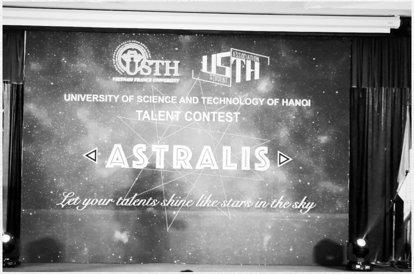
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Figure 2: Equalized

Extra 9b: Histogram Equalization

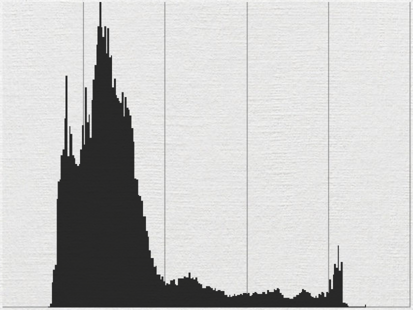
Figure 3: Original

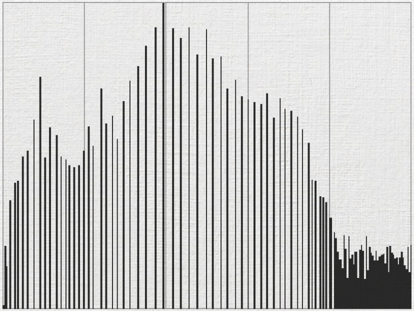
Figure 4: Equalized

Extra 9b: Histogram Equalization

- Calculate histogram `histo[]` (LW9a, GATHER + REDUCE)
- Let n be number of total pixels in the image
- Calculate probability of given intensity j (MAP)

$$p_j = \frac{histo_j}{n}, \forall j \in [0..255]$$

Extra 9b: Histogram Equalization

- Cumulative distribution function (CDF) c is calculated as [2]

$$c_i = \sum_{j=0}^{i} p_j$$

- Linearly scale $c_i \in [0..1]$ to $h_i \in [0..255], \forall i \in [0..255]$ (MAP)
- Original intensity i is transformed to h_i (MAP)
- We should have histogram equalized as now.

[2] c_i in this case should be calculated using parallel SCAN, but you haven't learnt about it yet. Let's do this step in sequential fashion.

Final Labwork: Fine-art transformation

- Implement Kuwahara filter, both with- and without- shared memory
- Write a report (in LaTeX)
    - Name it « Report.10.kuwahara.tex »
    - Explain how you implement the labworks
    - Explain and measure speedup
        - Without-shared memory vs CPU
        - With-shared memory vs without-shared memory
        - Other optimizations? Bank conflict? Coalesced access?
- Push the report and your code to your forked repository

Final Labwork: Fine-art transformation

- Kuwahara filter [wikipedia]
  - Reduces noise
  - Keeps edge
  - Also produces oil effect
  - Requires a lot of computation!

Final Labwork: Fine-art transformation

- Parameter ω as window size
- Convert RGB to HSV (SCATTER)
- For each pixel $\Phi(i, j)$
  - Define use 4 windows $W^k, k \in [1..4]$ of size $(\omega + 1) \times (\omega + 1)$
  - $W^1_x \in [i - \omega, i], W^1_y \in [j - \omega, j]$
  - $W^2_x \in [i, i + \omega], W^2_y \in [j - \omega, j]$
  - $W^3_x \in [i - \omega, i], W^3_y \in [j, j + \omega]$
  - $W^4_x \in [i, i + \omega], W^4_y \in [j, j + \omega]$

Final Labwork: Fine-art transformation

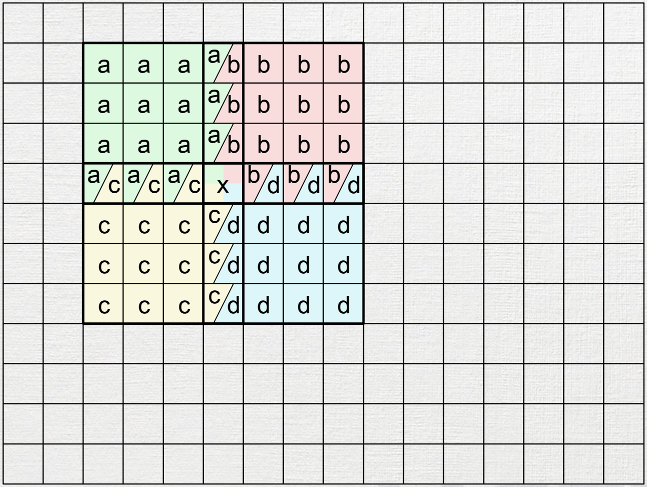

Figure 5: Example $\omega = 3$

Final Labwork: Fine-art transformation

- Find $W_l, l \in [1..4]$ having lowest standard deviation of brightness.
  - Use V in HSV color space to calculate SD.
- Assign mean (R, G, B) value of this window $\mid W_l \mid_{RGB}$ as new color (REDUCE, MAP)

$$\Phi(i,j)_{RGB} = \mid W_l \mid_{RGB}$$

Good luck & Have fun