Approximate Computing and Data Analysis

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Introduction

- Sometimes, computing the best possible output of some algorithm requires a significant amount of resources
- For some applications, the best possible output is not actually needed, since minor degradations will possibly not even be recognized by users.
- This can be exploited in a resource-constrained environment in order to trade-off the quality of the output against resources.
- A certain deviation of the actual output is accepted, for example, for lossy audio, video and image encoding.

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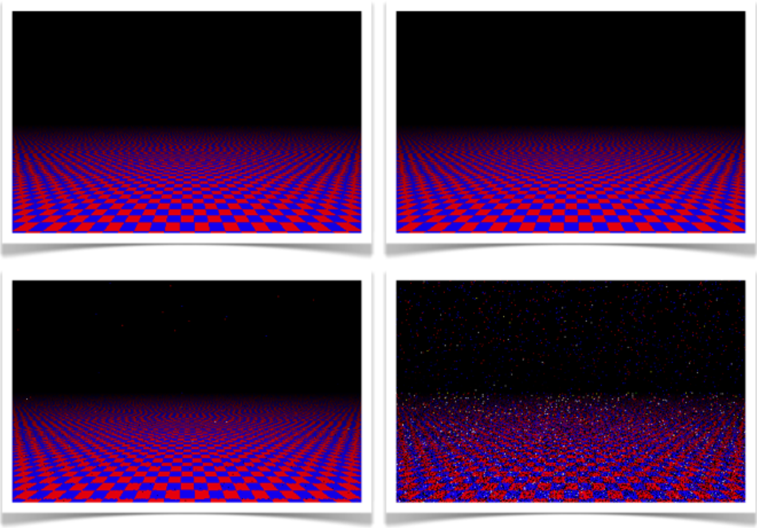
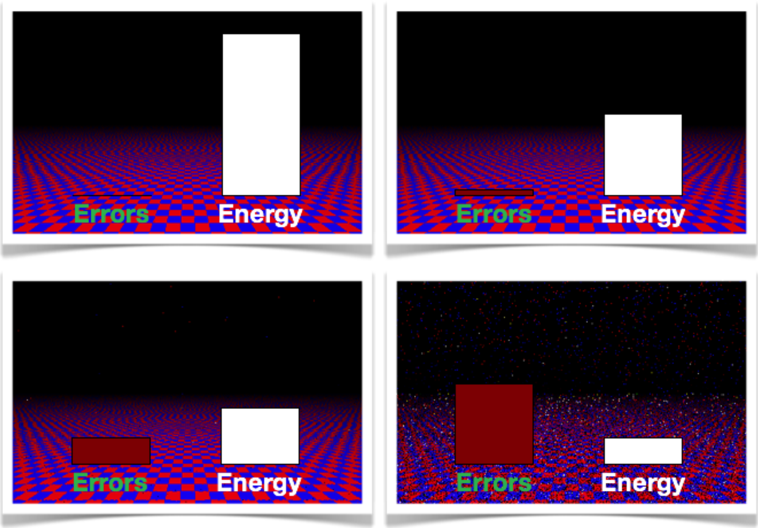
This leads us to consider approximate computing

An Example



slides from Sampson et al. 2013.

An Example



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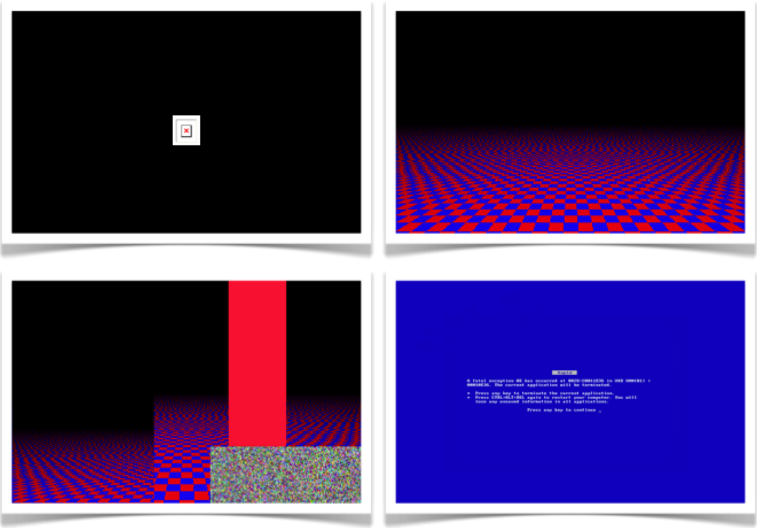

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Definition

According to, Mittal, S.: "A survey of techniques for approximate computing." ACM Comput. Surv. 48(4), 62:1-62:33 (2016).

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Computing which tolerates a certain deviation of generated output of some algorithm from the best possible result is called approximate computing

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It is essential to compare the best possible output (real) values x_1, x_2, ..., x_n with the approximated output (signal) values y_1, y_2, ..., y_n, for n samples.

Possible Metrics to Compare $\vec{x}$ and $\vec{y}$

Definition

The Mean-Squared Error (MSE) is defined as

$$MSE(\vec{x}, \vec{y}) = \frac{1}{n} \sum_{i=1}^{n} (x_i - y_i)^2$$

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Definition

The Root-Mean-Squared Error (RMSE) is defined as

$$RMSE(\vec{x}, \vec{y}) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - y_i)^2}$$

Possible Metrics to Compare $\vec{x}$ and $\vec{y}$ (cont.)

Definition

The Mean-Absolute Error (MAE) is defined as

$$MAE(\vec{x},\vec{y}) = \frac{1}{n}\sum_{i=1}^{n}|x_i - y_i|$$

For identical deviations of the measured signal y from real values x, the MAE is equal to the RMSE. However, the RMSE emphasizes large deviations between real and measured values (so-called outliers).

Peak Signal to Noise Ratio

Definition

The Peak-Signal-to-Noise Ratio (PSNR) is defined as

$$PSNR(\vec{x}, \vec{y}) = 10 \log_{10} \left(\frac{x_{max}^2}{MSE(x, y)} \right) = 20 \log_{10} \left(\frac{x_{max}}{RMSE(x, y)} \right)$$

where x_{max} is defined as the $\max_{i=1}^{n} x_i$

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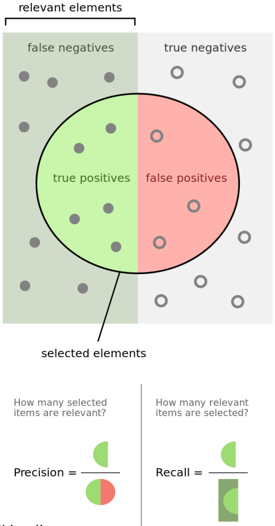
- There are several other metrics, especially for images
- None of these metrics is really superior to others
- Several of these metrics should be computed and a careful comparison should be performed

Data Analysis in Approximating Computing

- For data analysis, classification of objects is a frequent goal
- Suppose that we restrict ourselves to binary classification
- Four cases are possible
  - True positives (TP): we classify some object as a cat and it is actually a cat
  - False positives (FP): we classify some object as a cat and it is not a cat
  - True negatives (TN): we classify some object as not a cat and it is actually not a cat
  - False negatives (FN): we classify some object as not a cat and it is actually a cat.

Precision and Recall



Wikipedia

Definition

The precision is defined as

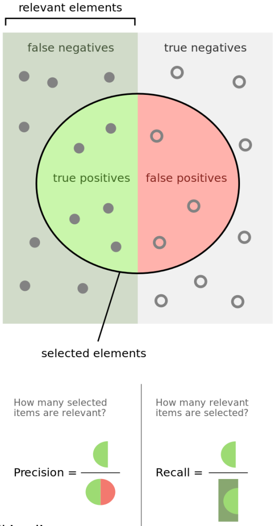
$$\frac{\text{True Positives}}{\text{True Positives} + \text{False Positives}}$$

Definition

The recall is defined as

$$\frac{\text{True Positives}}{\text{True Positives} + \text{False Negatives}}$$

Precision and Recall



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Definition

The recall is defined as

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Definition

The F1 score or F-measure is defined as the harmonic mean of precision and recall

Accuracy and Specificity

Definition

The accuracy is defined

$$\frac{\text{True Positives} + \text{True Negatives}}{\text{True Positives} + \text{False Positives} + \text{True Negatives} + \text{False Negatives}}$$

Definition

The specificity is defined

$$\frac{\text{True Negatives}}{\text{False Positives} + \text{True Negatives}}$$

Approximate Computing: Some Examples

- Qualifiers of data types
  - @approx int a := . . . ;
  - @precise int p := . . . ;
- Variable a is not accurate and variable p is accurate
- Statements
  - p := a; (this is problematic)
  - a := p; (this is okay)
- Approximate Conditions

  if (a = 10) { p :=2;} (this can be problematic, approximate bool)

Controlling Approximation

- Approximate should not interfere with precise
- Semantically, approximate results are unspecified best effort
- Only higher levels can measure quality, but application specific
- Lower (hardware or system software) levels can make monitoring convenient
- Offline: Profile, auto-tune
- Online: React, i.e., recompute or decrease the approximation level

Approximation-aware ISA

- An example (in MIPS ISA):

```
lw r1, 0x04($0)
lw r2, 0x08($0)
add r3, r1, r2
sw r3, 0x0c($0)
```

- An example (in Approximate MIPS ISA):

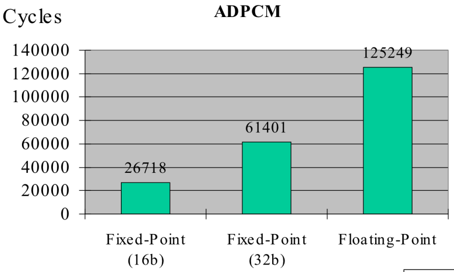
```
lw r1, 0x04($0)
lw r2, 0x08($0)
add.a r3, r1, r2
sw.a r3, 0x0c($0)
```

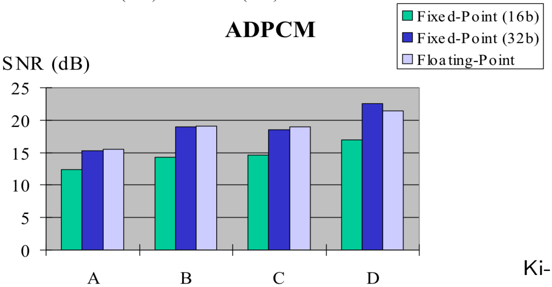
- add.a and sw.a need approximate ALU and approximate storage, respectively.

Floating-Point to Fixed-Point Conversion

- Pros:
  - Lower cost
  - Faster
  - Lower power consumption
  - Sufficient SNR, if properly used
  - Suitable for portable applications
- Cons:
  - Decreased dynamic range
  - Finite word-length effect, unless properly scaled
  - Overflow and excessive quantization noise
  - Extra programming effort

An Example: ADPCM





Ki-Il Kum, et al.