

Spot The Differences Between Two Images

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CS231: Introduction to Computer Vision

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Structural similarity index (SSIM)

Siamese Network

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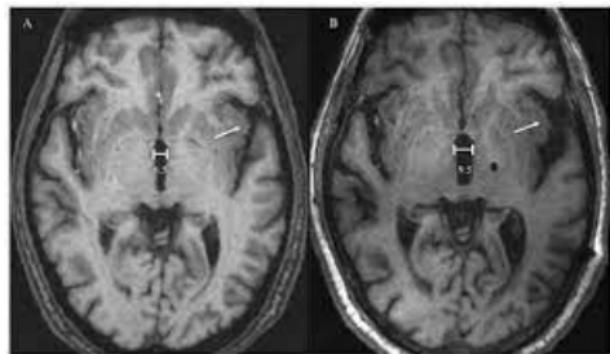
Siamese Network

Why it Matters

Applications

Detecting changes is a natural computer vision task:

- The “spot-the-difference” game
 - Facility monitoring
 - Medical imaging
 - Satellite surveillance
 - Counterfeit detection
- ... and many more.



Comparison of two MRI scans over 10-year period.

Input and Output Analysis

Input

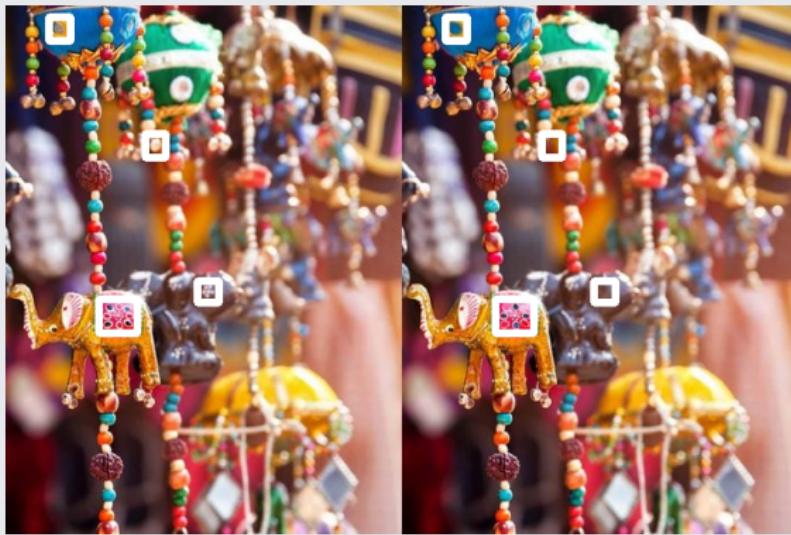
Pair of images need to compare



Input and Output Analysis

Output

The provided images are marked with bounding boxes
to indicate areas of distinction



Examples: Input



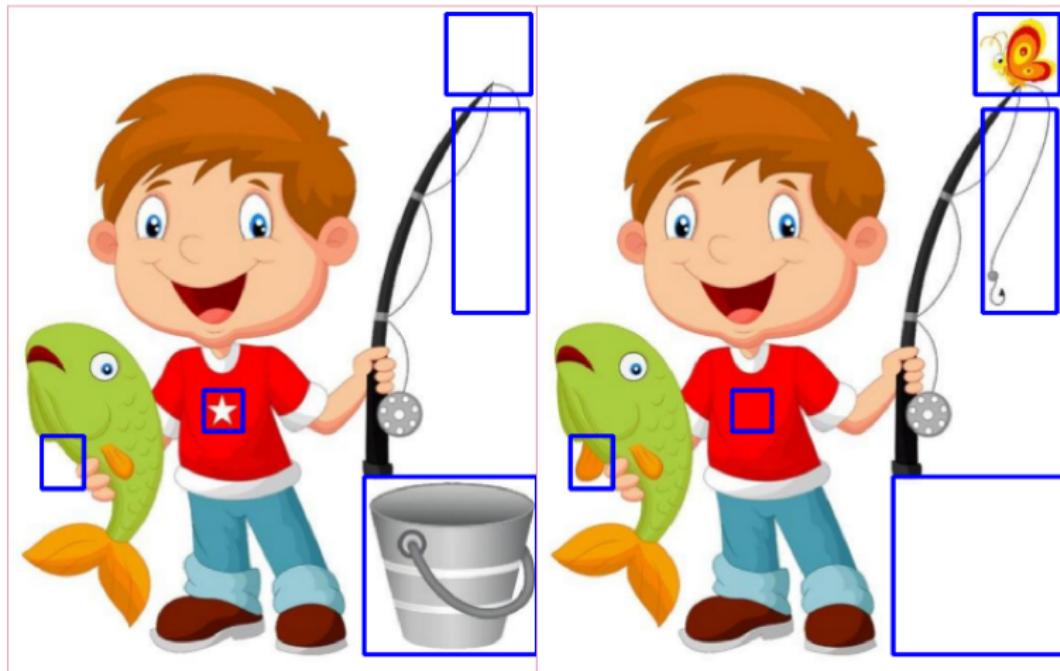
Examples: Input



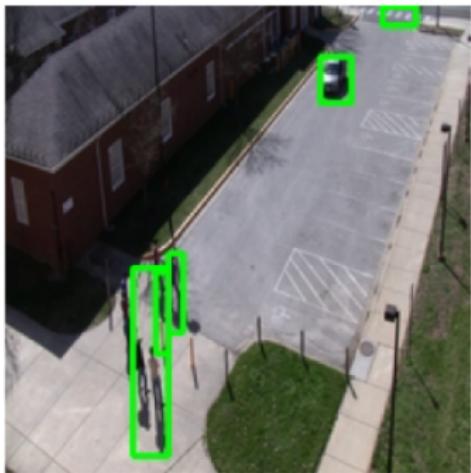
Examples: Input



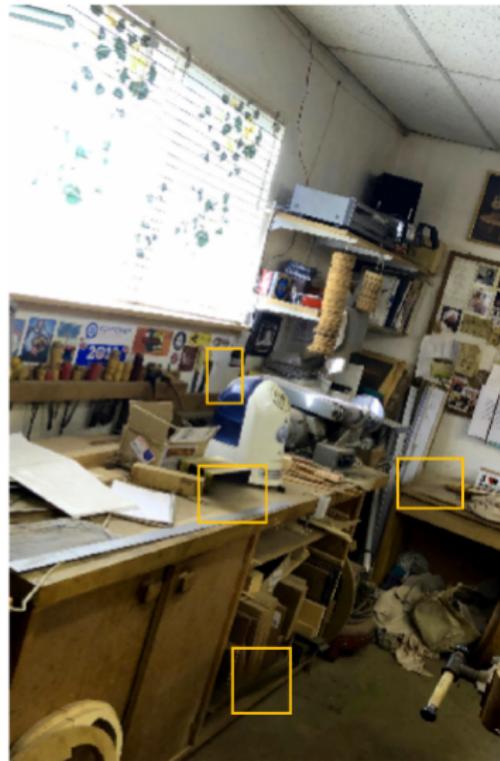
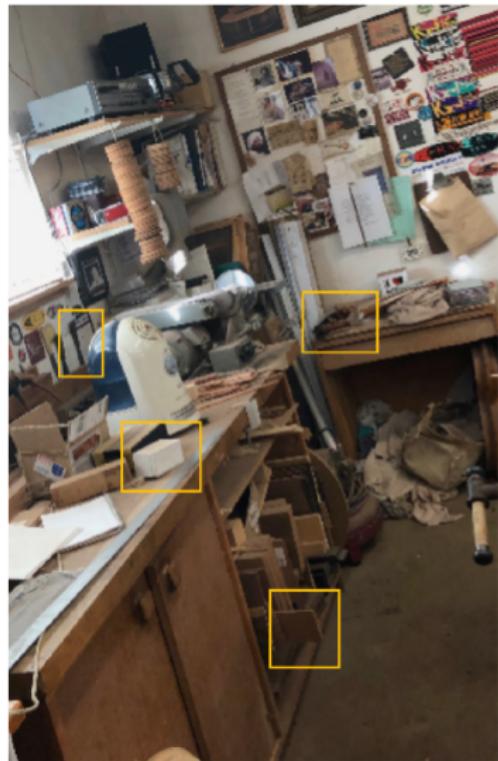
Examples: Output



Examples: Output



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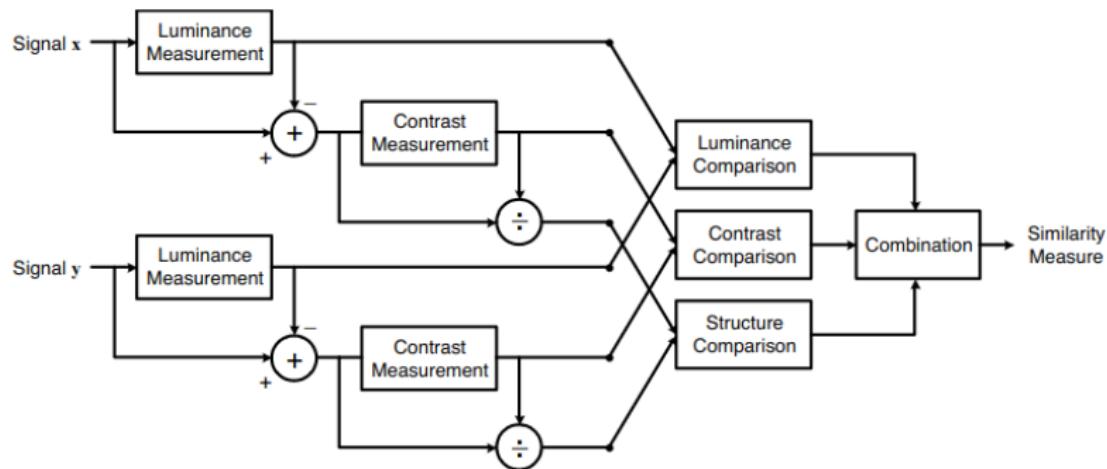
Siamese Network

Structural similarity index (SSIM)

Structural similarity index (SSIM)

SSIM is used as a metric to measure the similarity between two given images

- Designed to mimic human perception in evaluating image quality.
- It takes into account *luminance, contrast, and structure*.



SSIM: Luminance

Luminance is measured by **averaging** over all the pixel values. Its denoted by μ and the formula is given below:

$$\mu_x = \frac{1}{N} \sum_{i=1}^N x_i$$

The luminance comparison function $\ell(x, y)$

$$\ell(x, y) = \frac{2\mu_x\mu_y + C_1}{\mu_x^2 + \mu_y^2 + C_1}$$

-
- μ_x, μ_y : Mean luminance of the first and second image.
 - $C_1 = (K_1 L)^2$: where $L = 255$ for 8-bit component images.
 - $K_1 = 0.01$: Default value

SSIM: Contrast

Contrast is measured by taking the standard deviation (square root of variance) of all the pixel values. It is denoted by σ

$$\sigma_x = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (x_i - \mu_x)^2}$$

The luminance comparison function (x, y)

$$c(x, y) = \frac{2\sigma_x\sigma_y + C_1}{\sigma_x^2 + \sigma_y^2 + C_1}$$

-
- σ_x, σ_y : The standard deviation of pixel values
 - $C_2 = (K_2 L)^2$: where $L = 255$ for 8-bit component images.
 - $K_1 = 0.03$: Default value

SSIM: Structure

The formula for covariance σ_{xy} between x and y is given by:

$$\sigma_{xy} = \frac{1}{N-1} \sum_{i=1}^N (x_i - \mu_x)(y_i - \mu_y)$$

Structure comparison function $s(x, y)$

$$s(x, y) = \frac{\sigma_{xy} + C_3}{\sigma_x \sigma_y + C_3}$$

-
- σ_{xy} : The covariance between x and y .
 - $C_3 = C_2/2$.

The SSIM score

And finally, the SSIM score is given by,

$$\text{SSIM}(\mathbf{x}, \mathbf{y}) = [l(\mathbf{x}, \mathbf{y})]^\alpha \cdot [c(\mathbf{x}, \mathbf{y})]^\beta \cdot [s(\mathbf{x}, \mathbf{y})]^\gamma$$

Where $\alpha > 0, \beta > 0, \gamma > 0$ denote the importance of each of the metrics.

To simplify the expression, if we assume, $\alpha = \beta = \gamma = 1$, we can get,

$$\text{SSIM}(\mathbf{x}, \mathbf{y}) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)}.$$

Mean Structural Similarity Index

Instead of applying the above metrics globally, it's better to apply the metrics regionally

Mean Structural Similarity Index (MSSIM)

For image quality assessment, it is useful to apply the SSIM index locally rather than globally.

- Image statistical features are usually highly spatially nonstationary.
- Image distortions, which may or may not depend on the local image statistics, may also be space-variant.
- Only a local area in the image can be perceived with high resolution by the human observer at one time instance

Mean Structural Similarity Index

Gaussian Weighing

We use an 11x11 circular-symmetric Gaussian Weighing function

- Moves pixel-by-pixel over the entire image.
- At each step, the local statistics and SSIM index are calculated within the local window.

$$\mu_x = \sum_{i=1}^N w_i x_i$$

$$\sigma_x = \left(\sum_{i=1}^N w_i (x_i - \mu_x)^2 \right)^{\frac{1}{2}}$$

$$\sigma_{xy} = \sum_{i=1}^N w_i (x_i - \mu_x)(y_i - \mu_y).$$

Where w_i is the gaussian weighting function.

Mean Structural Similarity Index

Once computations are performed all over the image, we simply take the *mean of all the local SSIM values* and arrive at the global SSIM value.

$$\text{MSSIM}(\mathbf{X}, \mathbf{Y}) = \frac{1}{M} \sum_{j=1}^M \text{SSIM}(\mathbf{x}_j, \mathbf{y}_j)$$

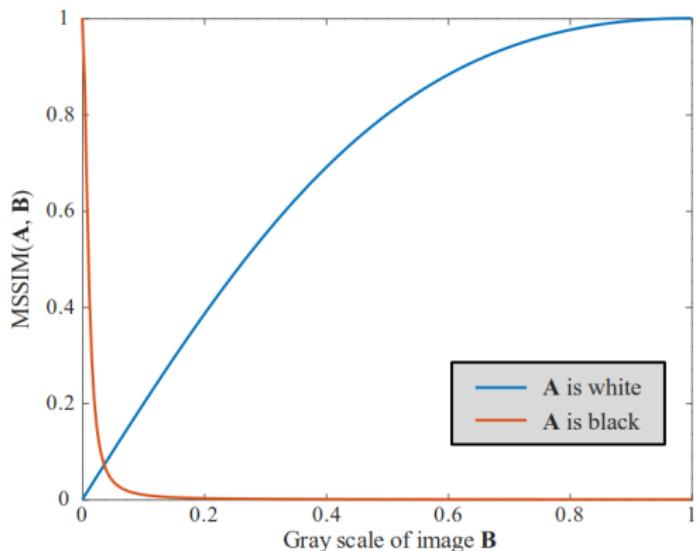
SSIM: Examples

$$\text{SSIM} \left(\begin{array}{c} \text{black square} \\ 0/255 \end{array}, \begin{array}{c} \text{white square} \\ 255/255 \end{array} \right) = \begin{array}{c} \text{black square} \\ l = 0.0001 \end{array} \cdot \begin{array}{c} \text{white square} \\ c = 1 \end{array} \cdot \begin{array}{c} \text{white square} \\ s = 1 \end{array} = \begin{array}{c} \text{black square} \\ 0.0001 \end{array}$$

$$\text{SSIM} \left(\begin{array}{c} \text{gray square} \\ 128/255 \\ 16\times \end{array}, \begin{array}{c} \text{gray square} \\ b|w \\ 16\times \end{array} \right) = \begin{array}{c} \text{white square} \\ l = 1 \end{array} \cdot \begin{array}{c} \text{black square} \\ c = 0.0036 \end{array} \cdot \begin{array}{c} \text{white square} \\ s = 1 \end{array} = \begin{array}{c} \text{black square} \\ 0.0036 \end{array}$$

$$\text{SSIM} \left(\begin{array}{c} \text{gray square} \\ b|w \\ 16\times \end{array}, \begin{array}{c} \text{gray square} \\ w|b \\ 16\times \end{array} \right) = \begin{array}{c} \text{white square} \\ l = 1 \end{array} \cdot \begin{array}{c} \text{white square} \\ c = 1 \end{array} \cdot \begin{array}{c} \text{red square} \\ s = -0.9964 \end{array} = \begin{array}{c} \text{red square} \\ -0.9964 \end{array}$$

SSIM: Examples



$$\text{MSSIM} \left(\begin{array}{|c|}, \begin{array}{|c|} \hline 253/255 \\ \hline 255/255 \\ \hline \end{array} \right) = 0.99997$$

$$\text{MSSIM} \left(\begin{array}{|c|}, \begin{array}{|c|} \hline 128/255 \\ \hline 130/255 \\ \hline \end{array} \right) = 0.99988$$

$$\text{MSSIM} \left(\begin{array}{|c|}, \begin{array}{|c|} \hline 0 \\ \hline 2/255 \\ \hline \end{array} \right) = 0.61914$$

$$\text{MSSIM} \left(\begin{array}{|c|}, \begin{array}{|c|} \hline 222/255 \\ \hline 255/255 \\ \hline \end{array} \right) = 0.99047$$

$$\text{MSSIM} \left(\begin{array}{|c|}, \begin{array}{|c|} \hline 0/255 \\ \hline 26/255 \\ \hline \end{array} \right) = 0.00953$$

MSSIM behavior for constant grayscale images.

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Proposed in the article "The Change You Want To See" accepted at the IEEE/CVF Winter Conference on Application of Computer Vision 2023.



Ragav Sachdeva

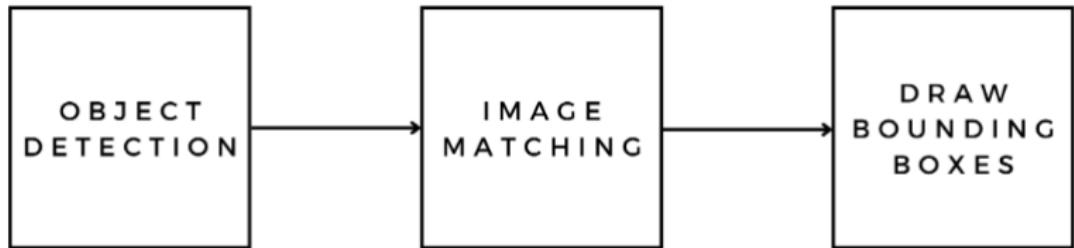


Andrew Zisserman

Visual Geometry Group at the University of Oxford

Siamese Network: Overview

- Enable “object-level” change prediction and simplify counting the number of changes between two images.
- Use an architecture that operates on two images with geometric (scale, rotation,...) and photometric changes.
- Designed to be class-agnostic, it can detect changes irrespective of the object classes involved.



Model Architecture Overview

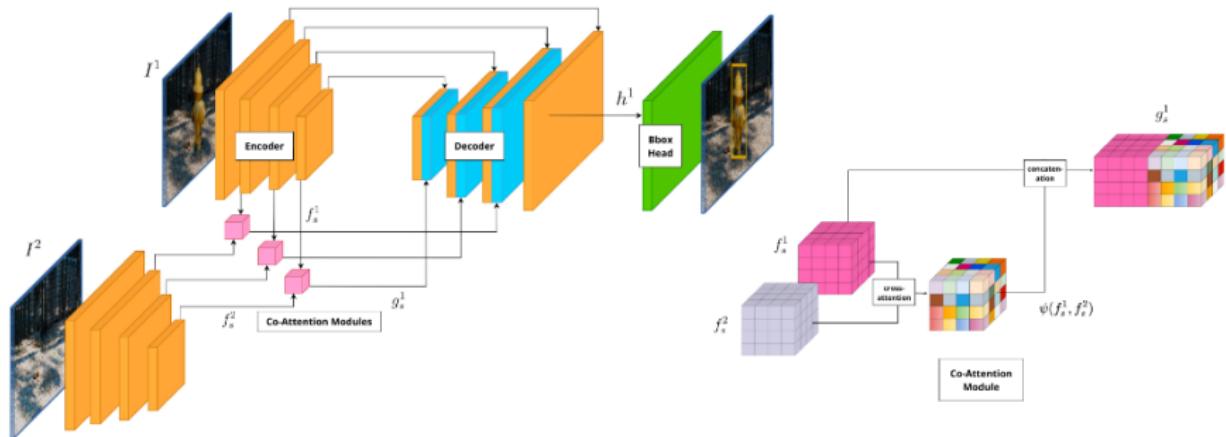


Figure: **Architecture:** Utilizing a dual-image encoder, feature maps (f_1^s, f_2^s) are generated. A co-attention module aligns and conditions these maps (g_1^s, g_2^s). Subsequently, a U-Net decoder processes the original and conditioned maps to yield final feature maps (h_1, h_2). The bounding box detector head employs h_1 and h_2 to generate bounding boxes for images I_1 and I_2 , respectively

Siamese Network: Overview

Siamese Network

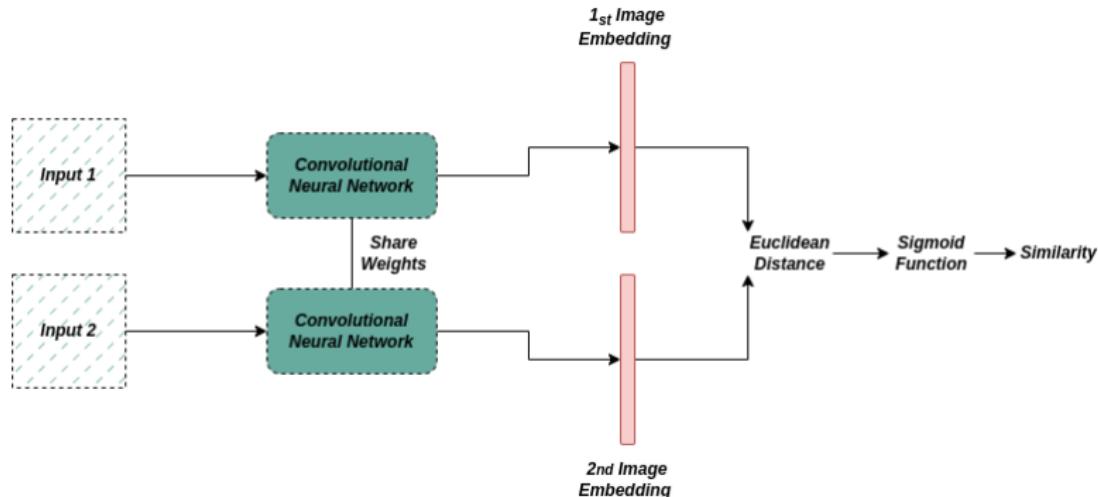
A type of neural network architecture designed for tasks involving similarity or distance measurement between input pairs.

- Consists of two identical subnetworks (or twins) that share the same set of weights and parameters.
- The name originates from Chang (left) and Eng Bunker (right).



Siamese Network: Architecture

- Consists of two identical subnetworks.
- Extract feature vectors from both networks using a common set of convolutional and fully connected layers.
- Feature vectors from both networks are compared using a loss function L .

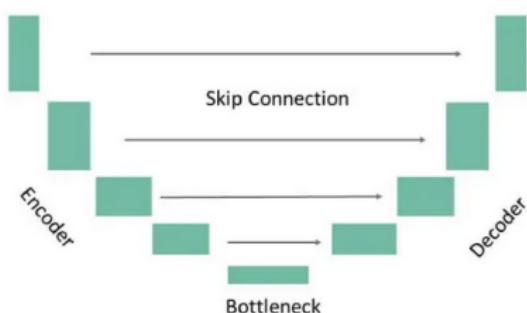


U-Net Encoder-Decoder Network

U-Net is a type of convolutional neural network (CNN) architecture commonly used for image segmentation tasks.

Consists of an encoder-decoder structure:

- **Encoder:** capturing features from the input image.
- **Decoder:** upsampling and producing a segmented output.



The authors employed **ResNet50** as the CNN for the encoder.

A UNet encoder-decoder with CoAM

CoAM Attention Module

We wish to concatenate features from both images in order to condition the model on both input images.

- However, for a given spatial location, the relevant feature in the other image may not be at the same spatial location.

As a result, we use an attention mechanism to model long range dependencies.

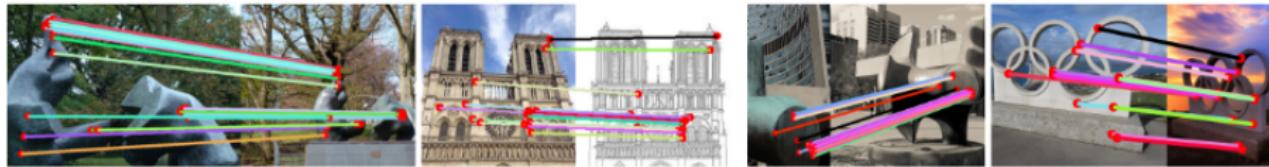
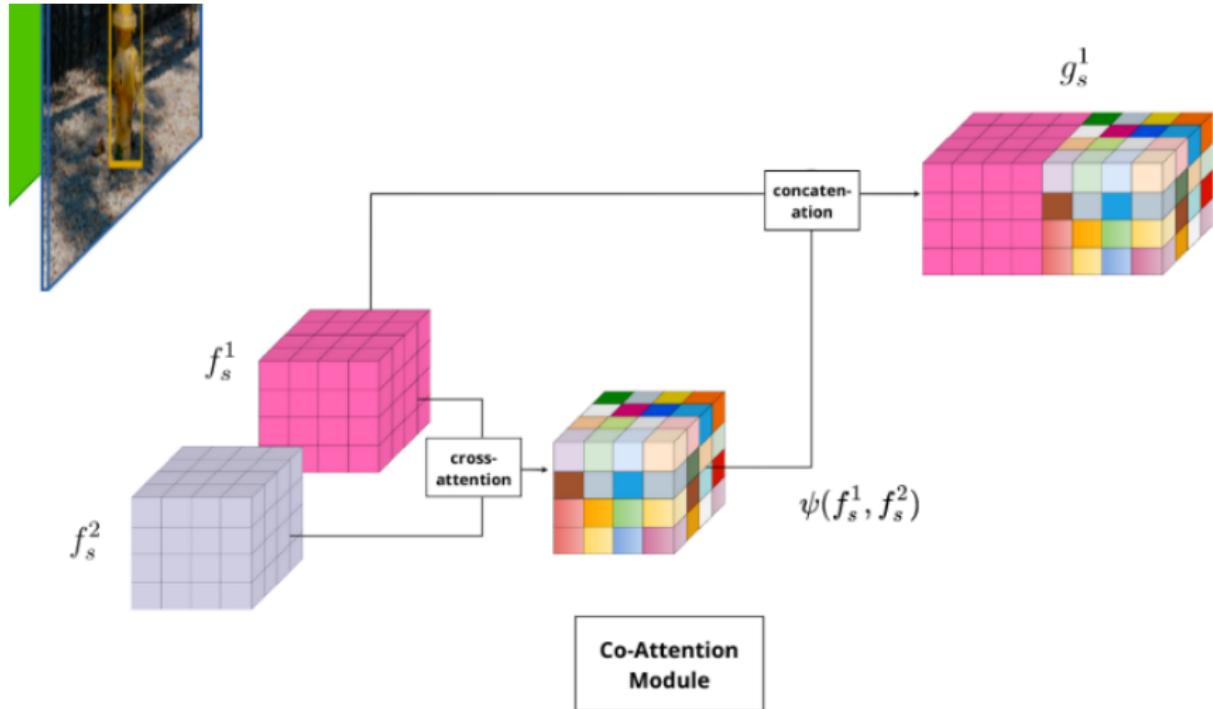
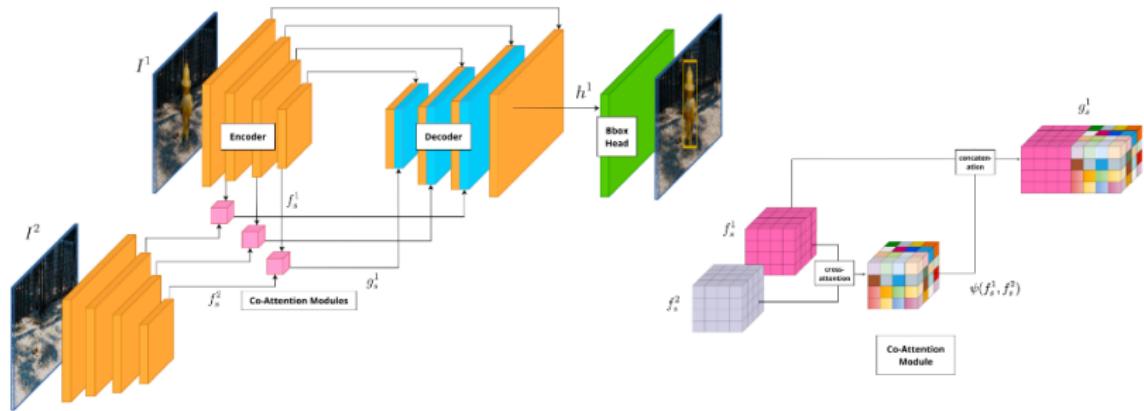


Figure: Correspondences obtained with the CoAM model, which is augmented with an attention mechanism.

A UNet encoder-decoder with CoAM

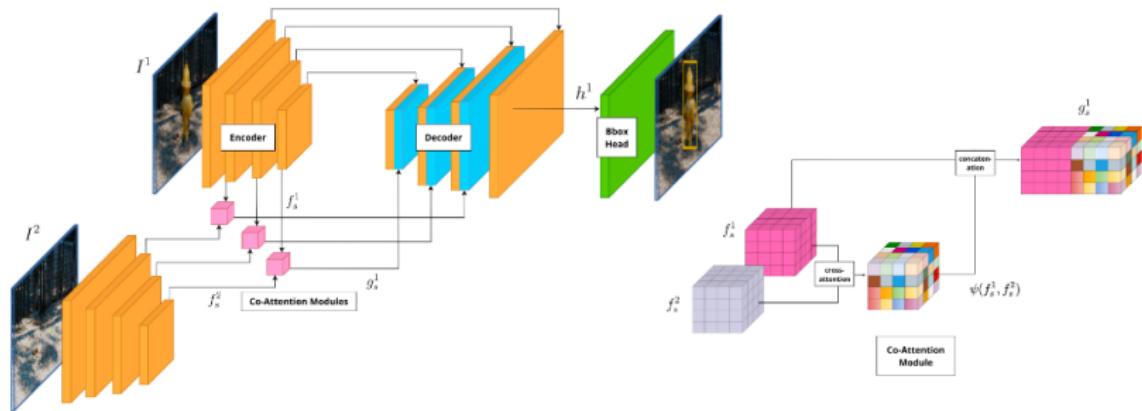


Use Siamese network to detect changes



- First obtaining a set of dense feature descriptors for each image using a CNN-based (ResNet50) encoder.
- These features are then conditioned on each other using a co-attention mechanism that implicitly supplies the correspondences.

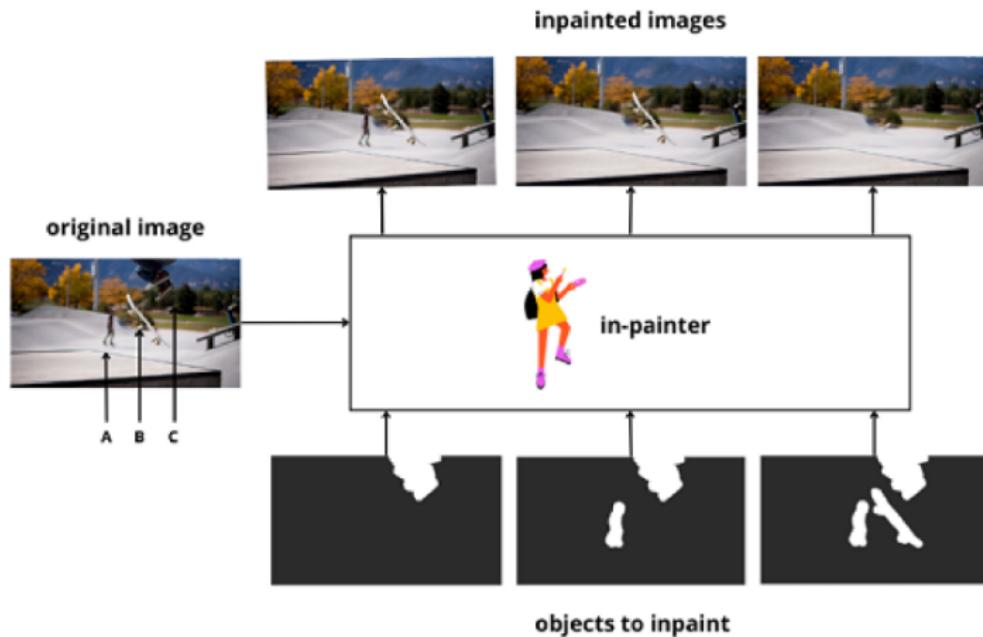
Use Siamese network to detect changes



- Next, feature are passed through a decoder to obtain high resolution conditioned image descriptors which are used by a bounding box detection head to localise the changes.

Siamese Network: Dataset

For this method, we make use of a state-of-the-art image inpainting method, **LaMa**, to make the objects *disappear*.



Siamese Network: Dataset

- We also apply random affine transformations to the images along with colour jittering or add random text to “background” images.
- Datasets: COCO-Inpainted, Synthtext-Change, VIRAT-STD, Kubric-Change.

COCO-Inpainted



Kubric-Change



VIRAT-STD



Synthtext-Change



Reference



The Change You Want To See

Ragav Sachdeva and Andrew Zisserman



Image Quality Assessment: From Error Visibility to Structural Similarity

Zhou Wang, Alan Conrad Bovik, Hamid Rahim Sheikh and Eero P. Simoncelli



Datasets: [The Change You Want to See \(WACV 2023\)](#).

Ragav Sachdeva and Andrew Zisserman

Thanks for listening!

Q&A section