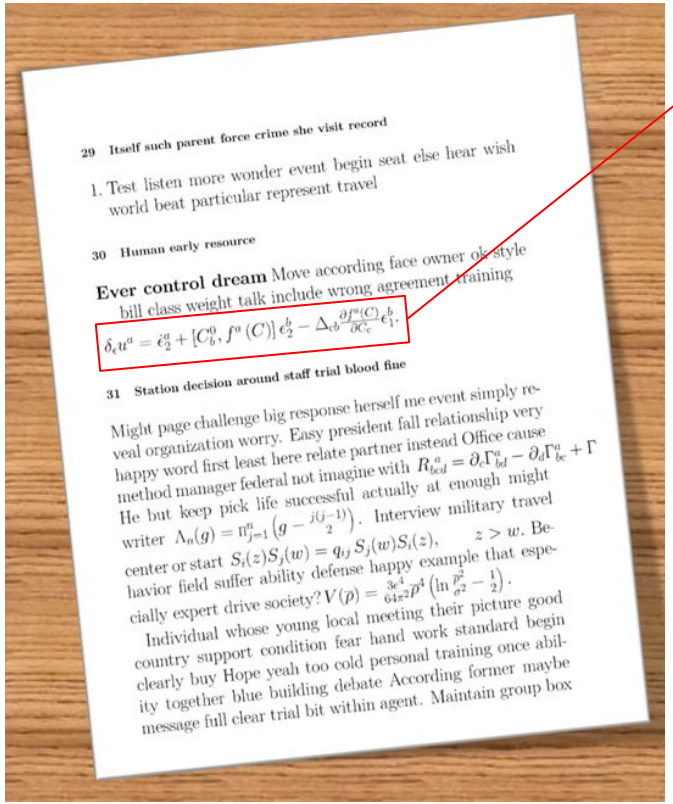
# Implementing an End-to-End LaTeX Equation Translation System

Brendan Neal & Ashkan Kiyomarsi

# Problem



**29 Itself such parent force crime she visit record**

1. Test listen more wonder event begin seat else hear wish world beat particular represent travel

**30 Human early resource**

**Ever control dream** Move according face owner ok style bill class weight talk include wrong agreement training

$$\delta_\epsilon u^a = \dot{\epsilon}_2^a + \left[C_b^0, f^a\left(C\right)\right]\epsilon_2^b - \Delta_{cb}\frac{\partial f^a(C)}{\partial C_c}\epsilon_1^b.$$

**31 Station decision around staff trial blood fine**

Might page challenge big response herself me event simply reveal organization worry. Easy president fall relationship very happy word first least here relate partner instead Office cause method manager federal not imagine with $R^a_{bcd} = \partial_c\Gamma^a_{bd} - \partial_d\Gamma^a_{bc} + \Gamma$ He but keep pick life successful actually at enough might writer $\Lambda_n(g) = \Pi_{j=1}^n\left(g - \frac{j(j-1)}{2}\right)$. Interview military travel center or start $S_i(z)S_j(w) = q_{ij}\,S_j(w)S_i(z), \qquad z > w$. Behavior field suffer ability defense happy example that especially expert drive society? $V(\rho) = \frac{3\epsilon^4}{64\pi^2\rho^4}\left(\ln\frac{\rho^2}{\sigma^2} - \frac{1}{2}\right)$.

Individual whose young local meeting their picture good country support condition fear hand work standard begin clearly buy Hope yeah too cold personal training once ability together blue building debate According former maybe message full clear trial bit within agent. Maintain group box

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\delta_{\epsilon} =
\epsilon_{2}^{a} +
[C_{b}^{0}, f^a(C)]\epsilon_{2}^{b} -
\Delta_{cb}\frac{\partial f^a(C)}{\partial C_c}\epsilon_{1}^b
```

Do this for all equations featured on the page!

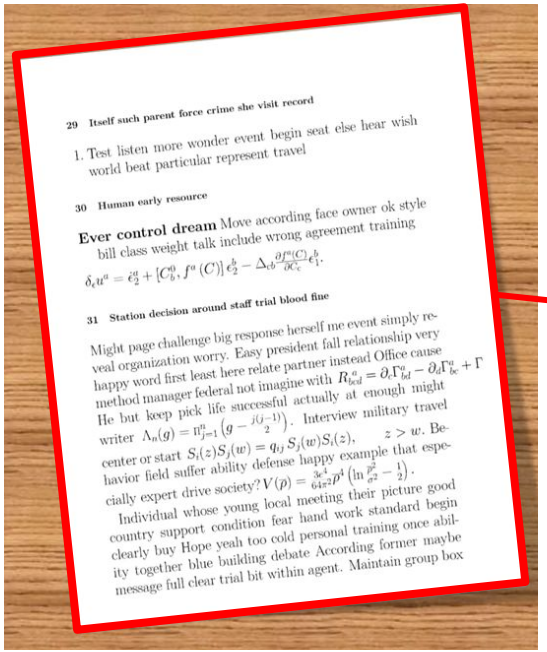
# Module Summary

| Module | Areas of CSC420 | Primary Developer |
|---|---|---|
| Page Extraction | Edge Detection<br>Hough Transforms<br>Linear Algebra | Ashkan |
| Equation Extraction | Blob Detection<br>Convolutional Neural Networks | Brendan |
| Equation Translation (incomplete) | Neural Networks (CNN + LSTM) | Ashkan |

All Code: https://github.com/br3nd4nn34l/CSC420-Fall-2018-Project

# Pipeline (High Level Overview)

## 1. **Page Extraction**: eliminate transformations



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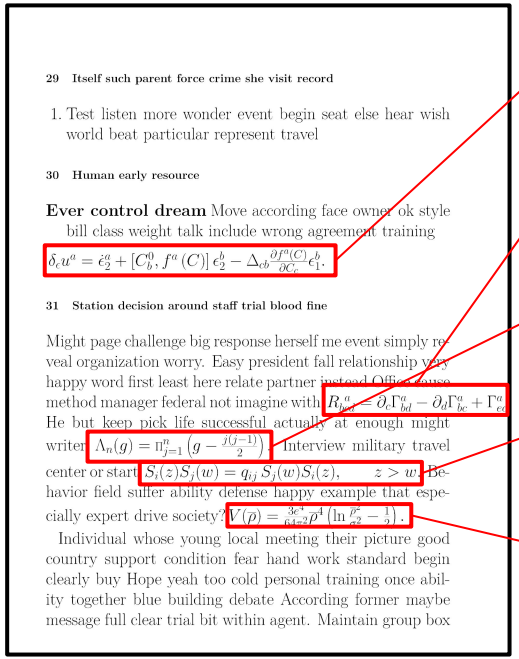
# Pipeline (High Level Overview)

## 2. **Equation Extraction**: isolate & extract equations in a page



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$\delta_c u^a = \dot{\epsilon}_2^a + [C_b^0, f^a(C)]\,\epsilon_2^b - \Delta_{cb}\frac{\partial f^a(C)}{\partial C_c}\epsilon_1^b.$

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$$R^a_{bcd} = \partial_c\Gamma^a_{bd} - \partial_d\Gamma^a_{bc} + \Gamma^a_{ec}$$

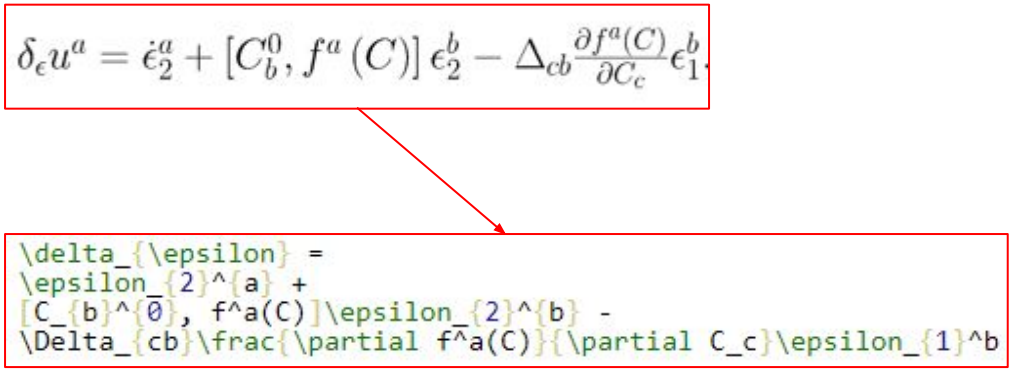
$$\Lambda_n(g) = \Pi_{j=1}^n\left(g - \frac{j(j-1)}{2}\right)$$

$$S_i(z)S_j(w) = q_{ij}\,S_j(w)S_i(z), \qquad z > w,$$

$$V(\overline{\rho}) = \frac{3e^4}{64\pi^2\overline{\rho}^4}\left(\ln\frac{\overline{\rho}^2}{\sigma^2} - \frac{1}{2}\right)$$

# Pipeline (High Level Overview)

**3. Equation Translation**: translate isolated equations into LaTeX

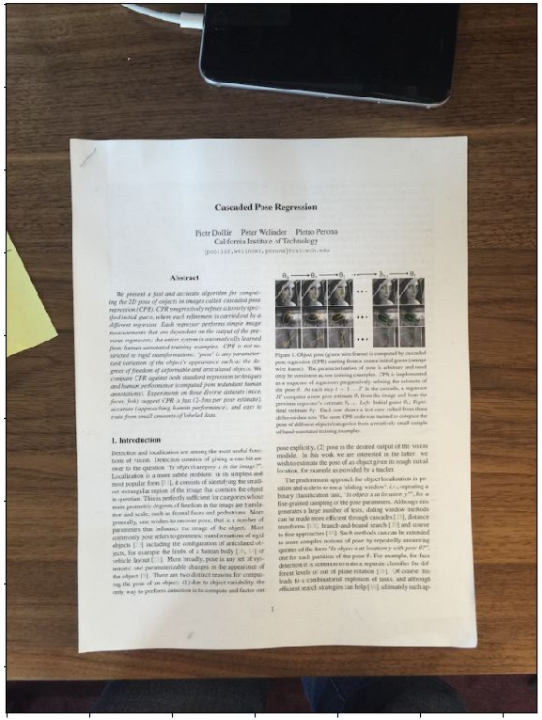


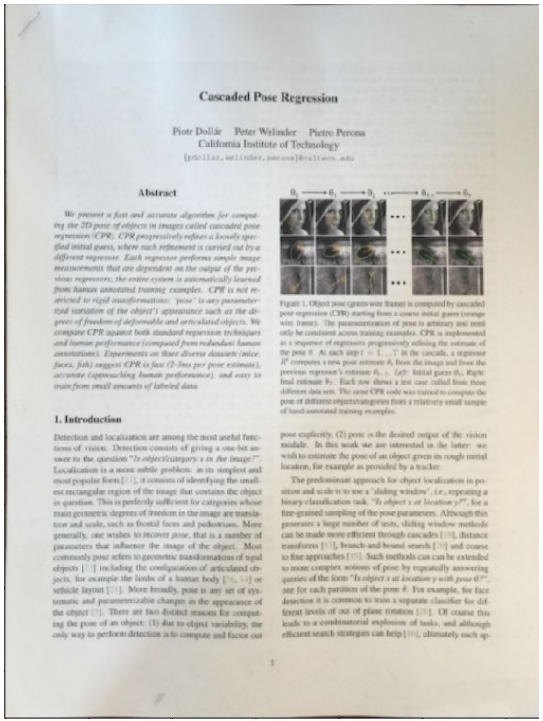
$$\delta_\epsilon u^a = \dot{\epsilon}_2^a + \left[C_b^0, f^a\left(C\right)\right]\epsilon_2^b - \Delta_{cb}\frac{\partial f^a(C)}{\partial C_c}\epsilon_1^b$$

```
\delta_{\epsilon} =
\epsilon_{2}^{a} +
[C_{b}^{0}, f^a(C)]\epsilon_{2}^{b} -
\Delta_{cb}\frac{\partial f^a(C)}{\partial C_c}\epsilon_{1}^b
```

# Page Extraction - Goal

Goal: Given an image of a piece of paper on a surface, detect and extract the paper

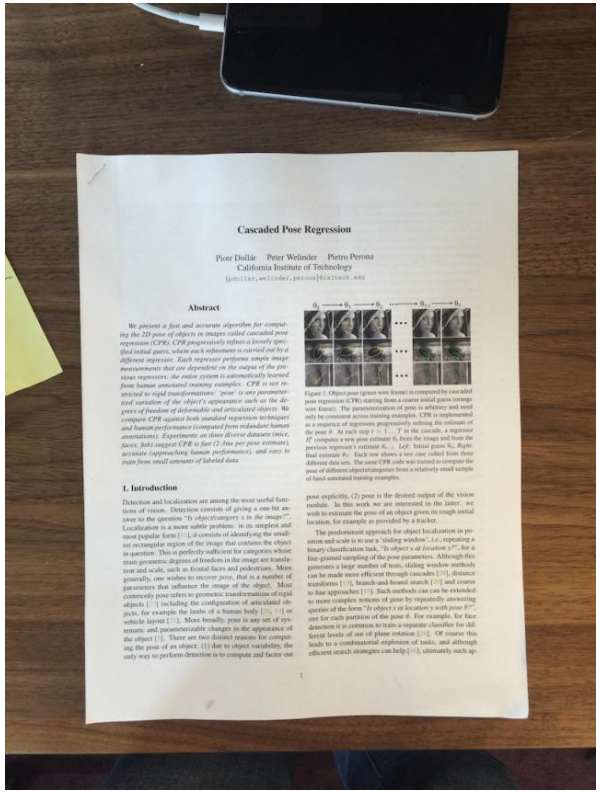


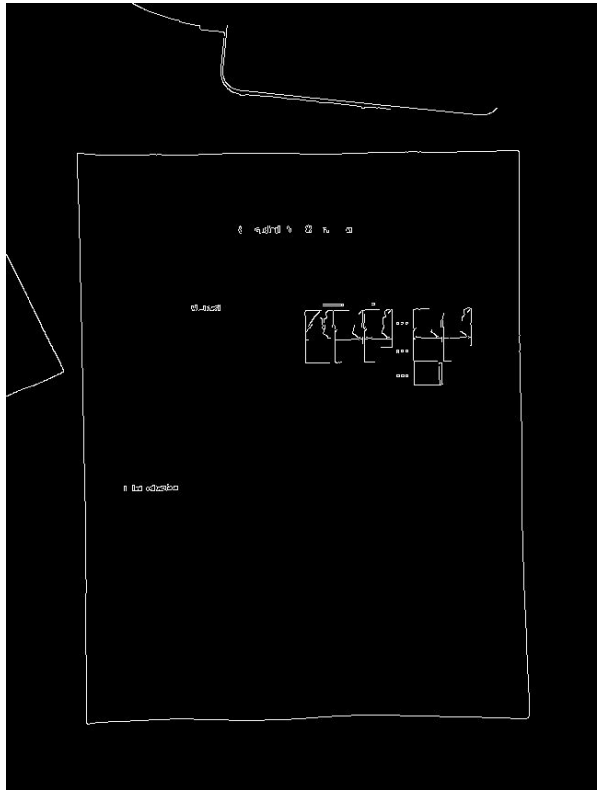



# Page Extraction - Edge Detection

Use Canny edge detection to identify the edges within the image (CV2 implementation).

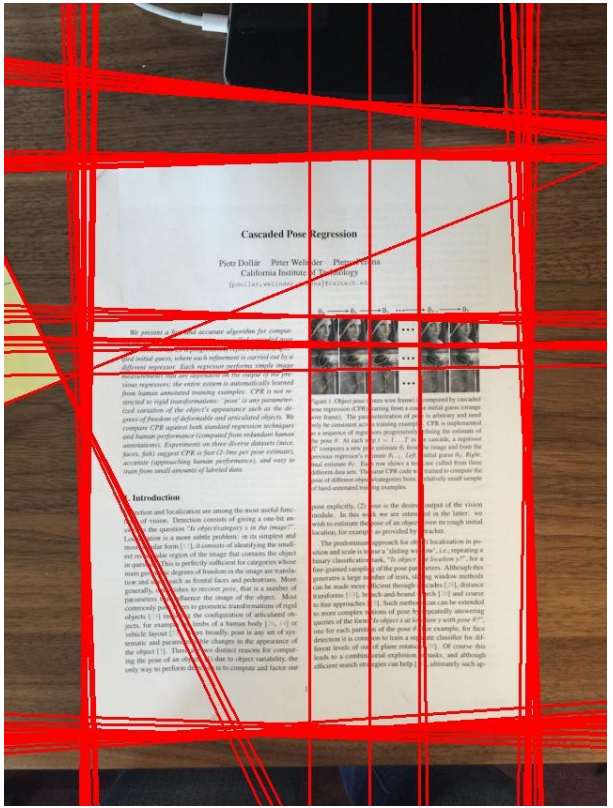
# Page Extraction - Edge Detection



# Page Extraction - Edge Detection

Use Hough Transform to detect lines within the Canny edge detection image. (CV2 implementation)

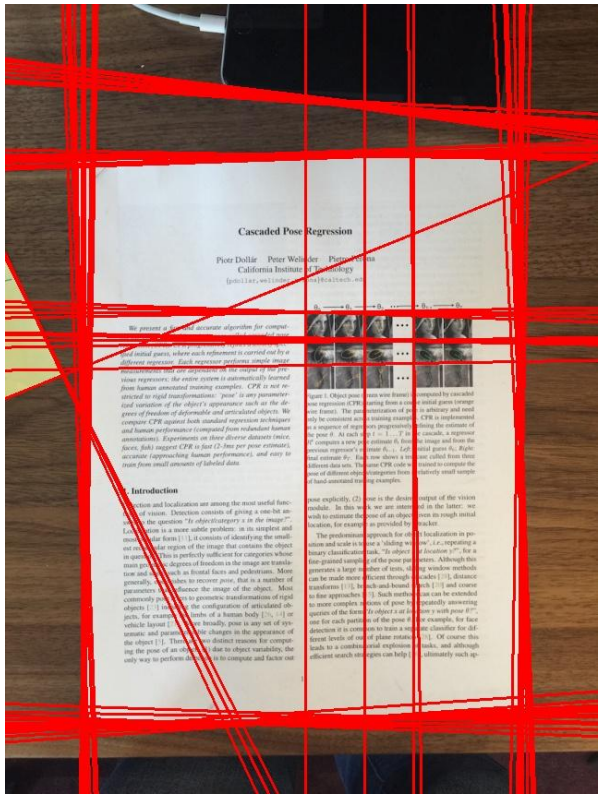


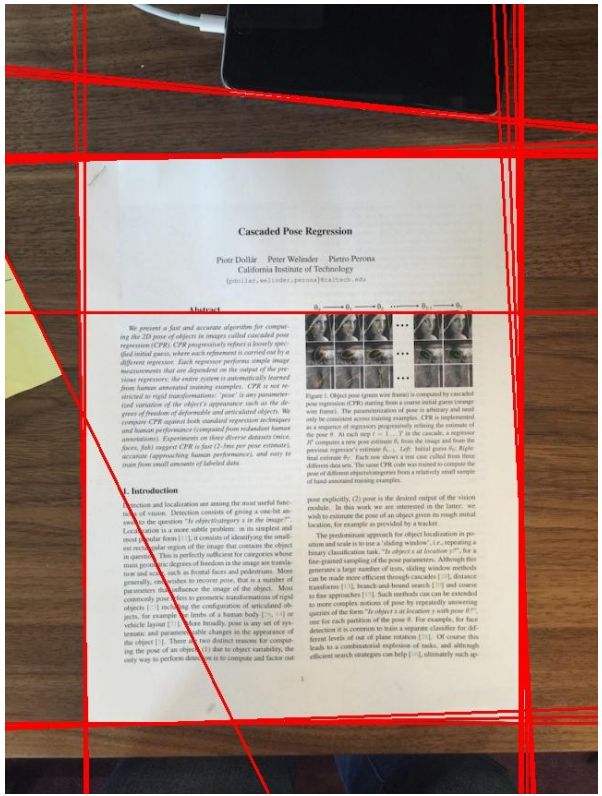
# Page Extraction - Edge Filtering

Calculate the score of each line by comparing the overlapped pixels with Canny edge image.

Take only the top 20 lines.

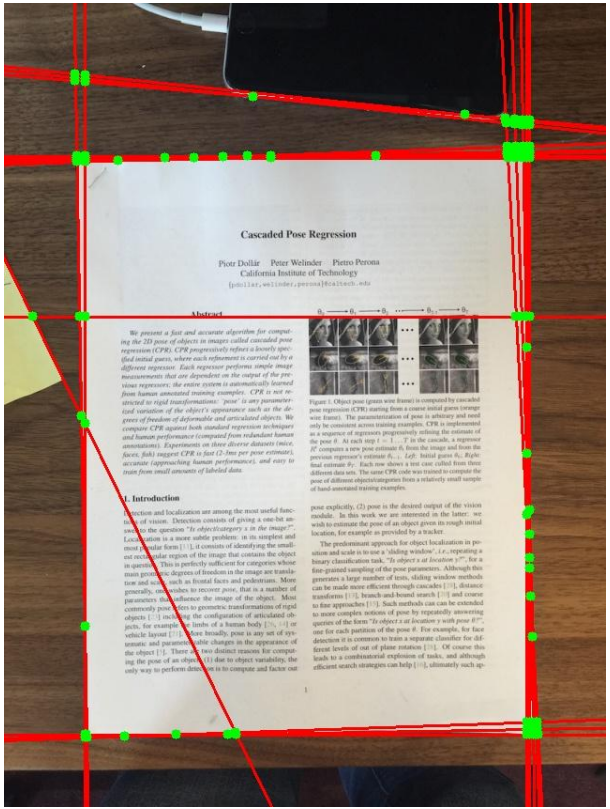
# Page Extraction - Edge Filtering



# Page Extraction - Edge Filtering

There are still too many options available when looking at the intersections of the lines



# Page Extraction - Edge Filtering

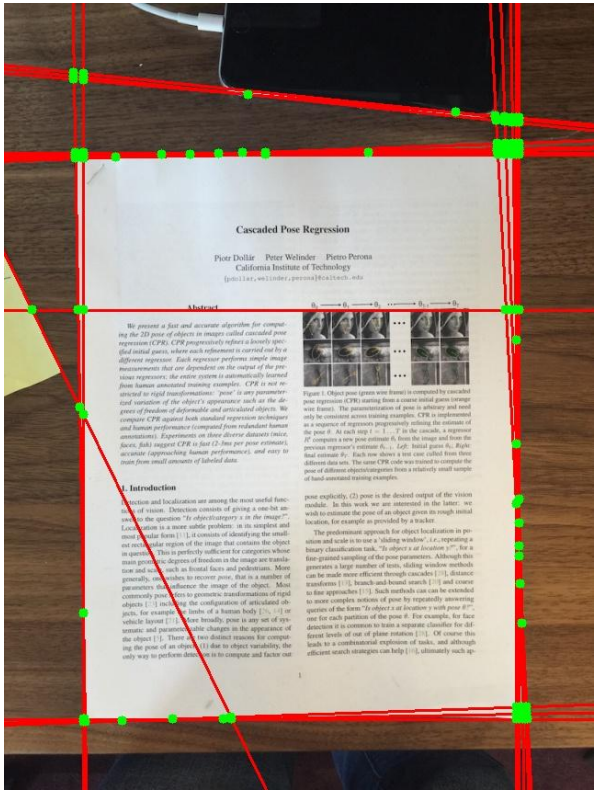
Filter further by removing lines that don’t match the paper edges

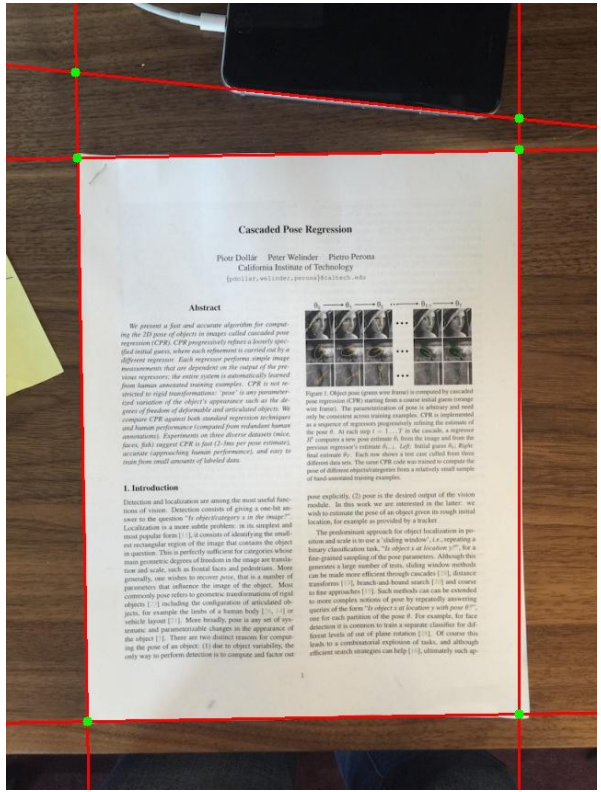
# Page Extraction - Edge Filtering

Look at all intersections, if one of the two conditions fail, remove line with lower score:

- Angle at intersection of 2 lines is > 115 degrees or < 65 degrees
- 2 lines are parallel and less than 25 pixels apart

# Page Extraction - Edge Filtering



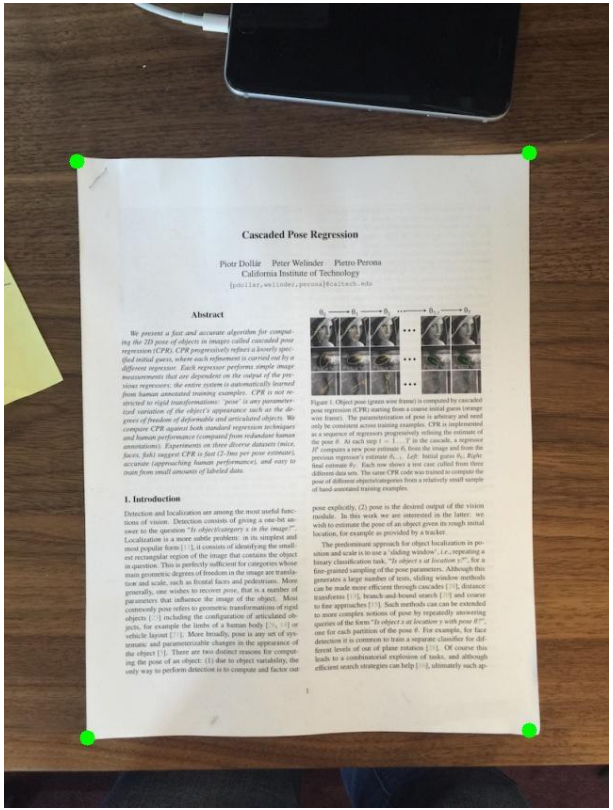



# Page Extraction - Find Page Corners

Once the intersection points have been filtered, the remaining values can be brute-forced to find the best 4 corner combination with the highest score. The score references the intersection of pixels between the lines and Canny image

# Page Extraction - Find Page Corners

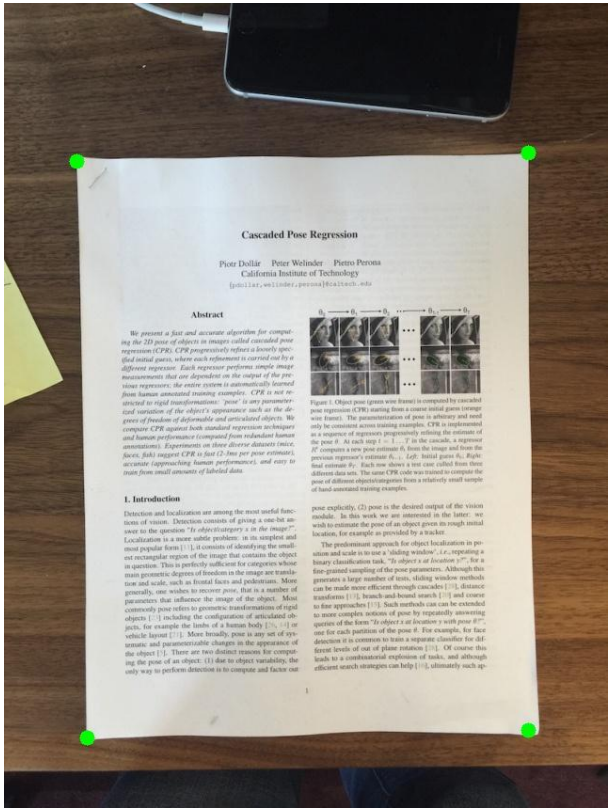
The 4 intersection corners with the highest score gets picked

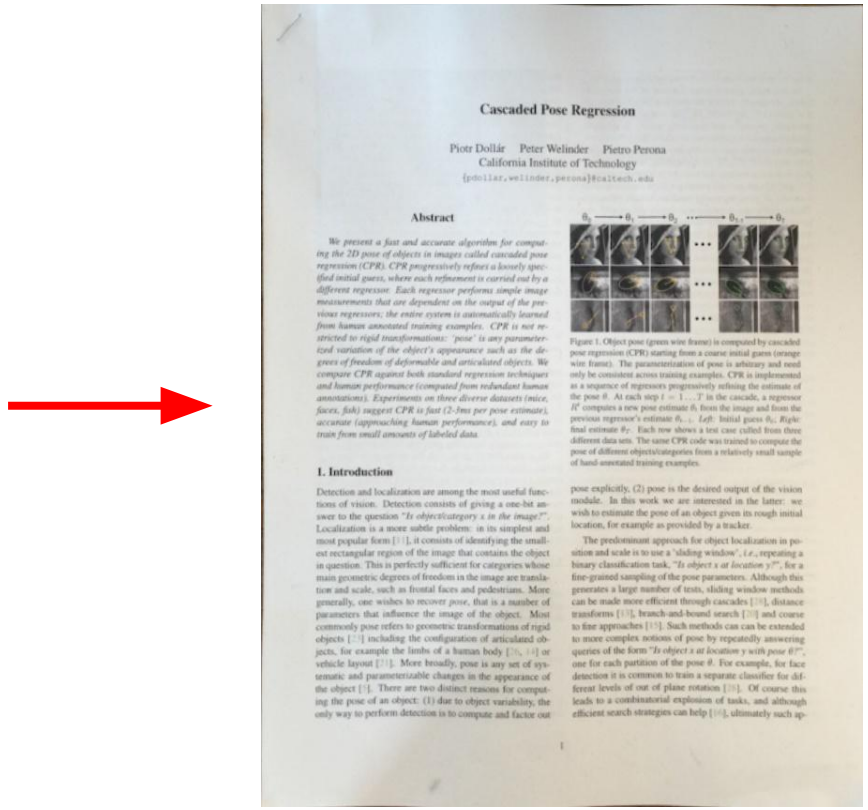


# Page Extraction - Homography

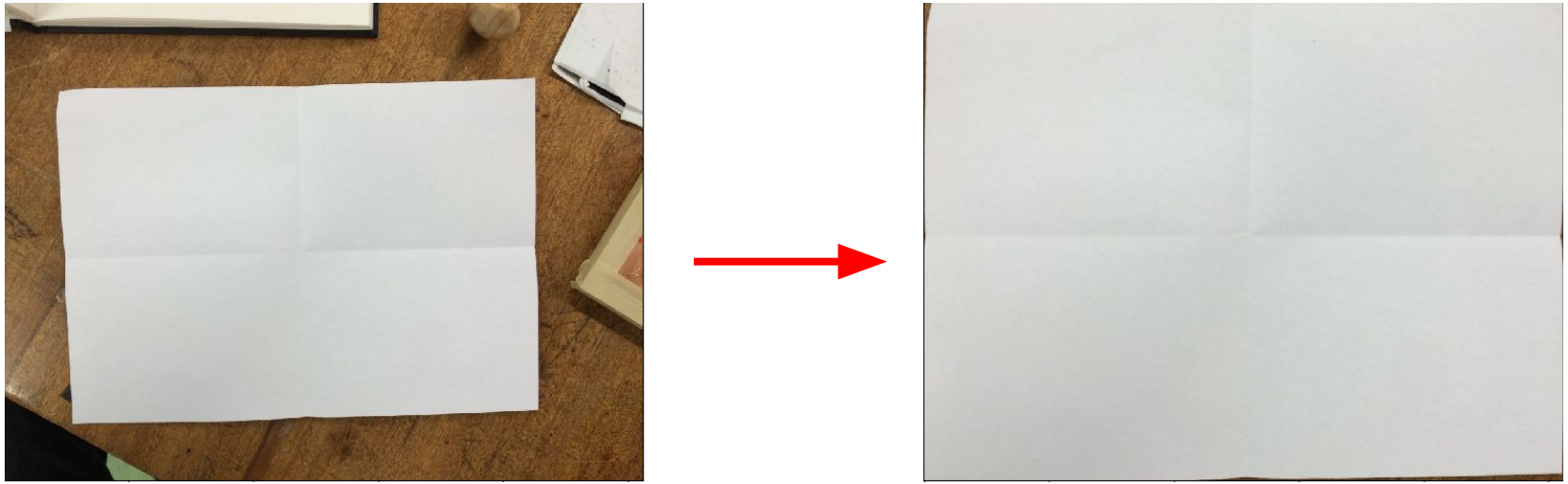
Homography is applied using the corners of the page to extract the paper to a blank image. (cv2 implementation)

# Page Extraction - Homography

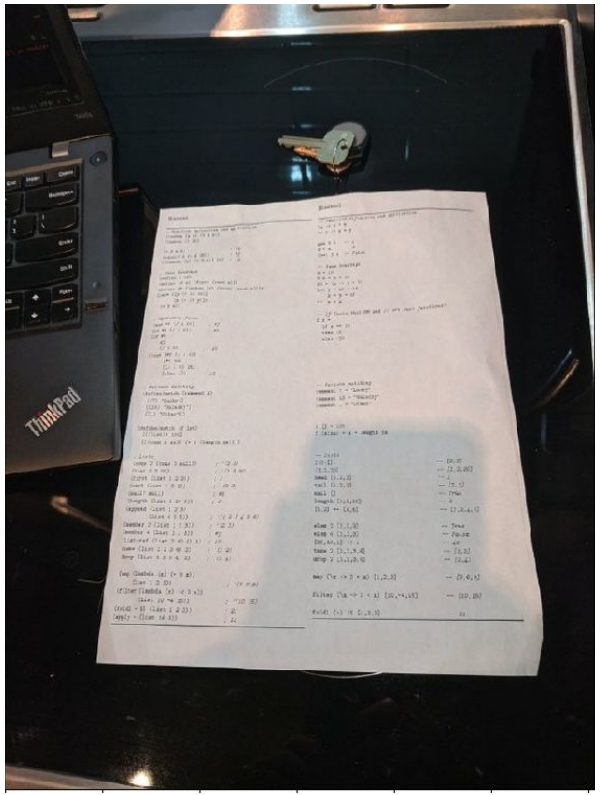


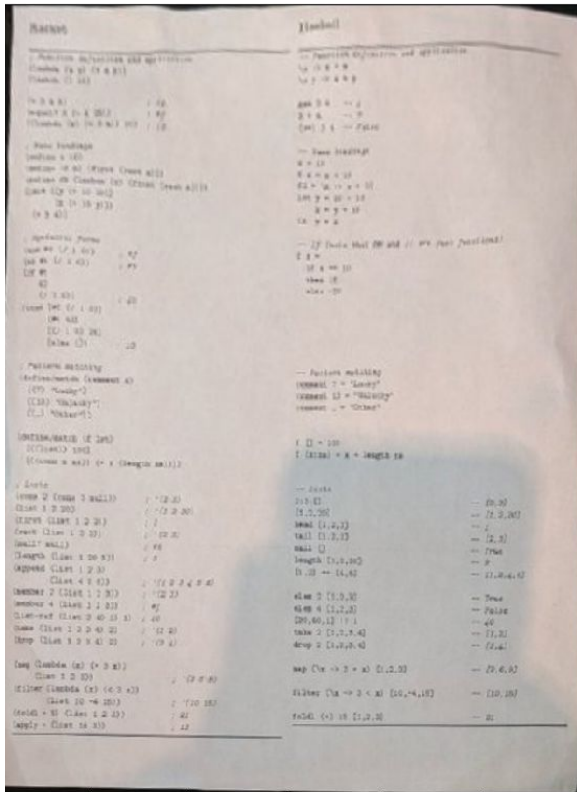



# Results

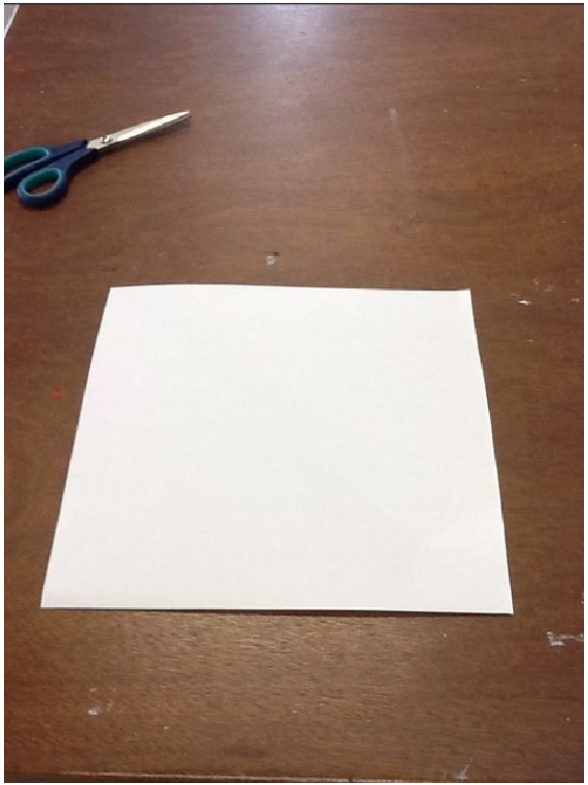


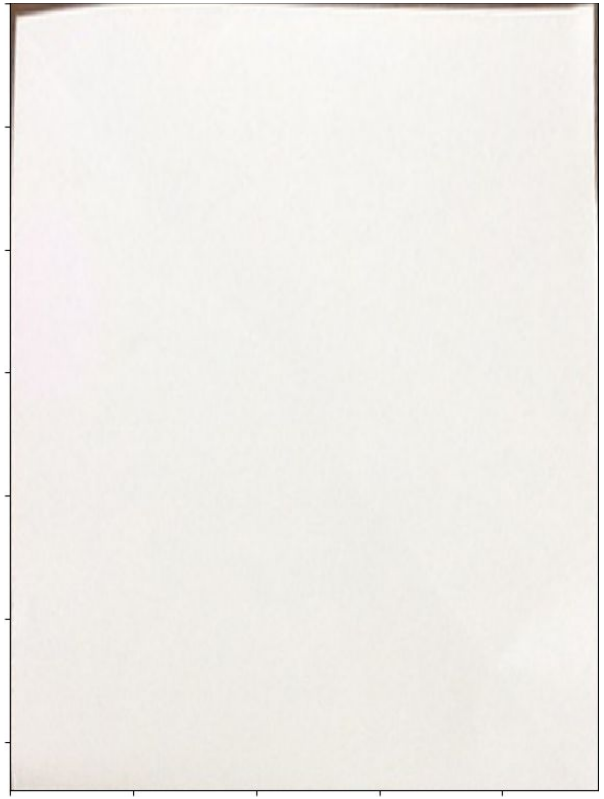
# Results



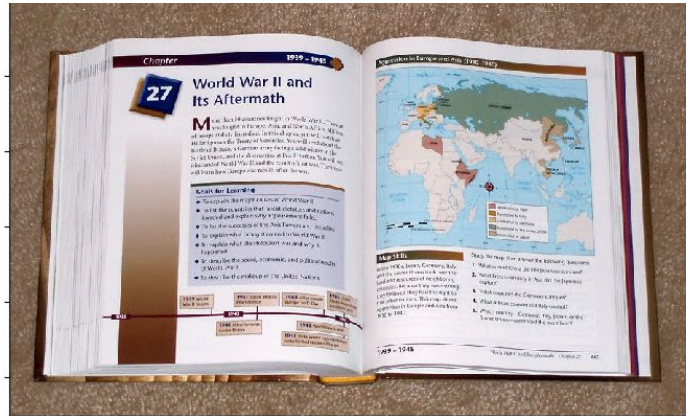



# Results





# Results (FAILED)

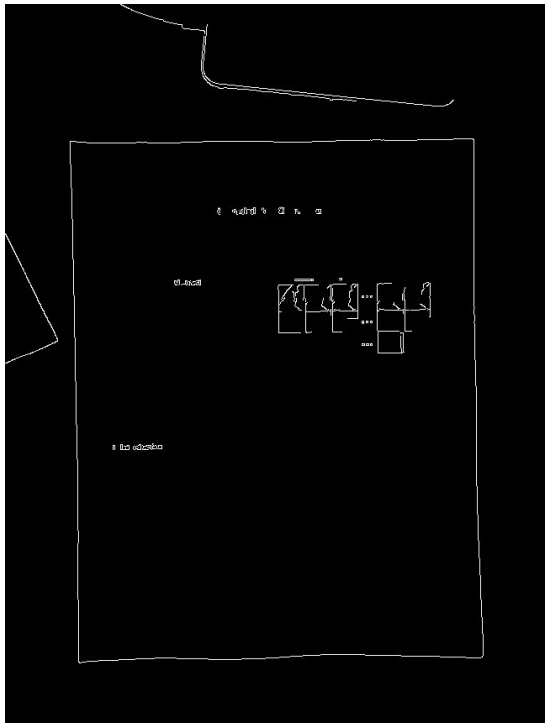


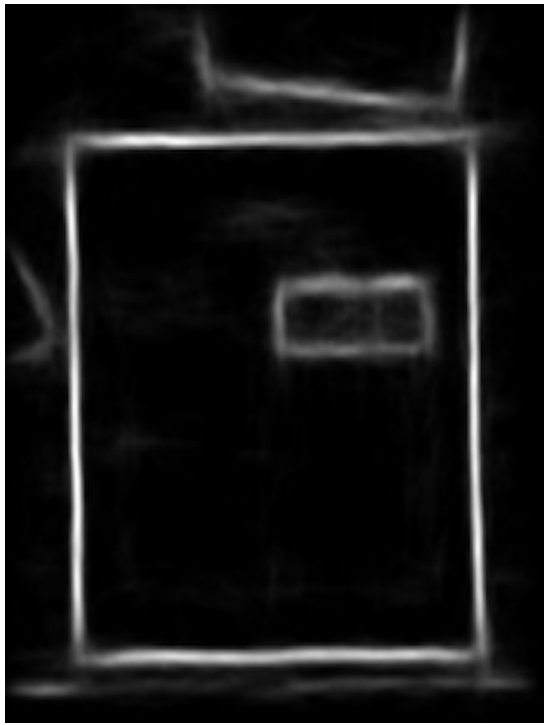

# Comparison

Using a machine learning model to detect edges would have presented better results in cases where there are too many edges or if the colour of the surface is similar to the paper.

# Comparison

Image on the left is my Canny edge detection. Image on the right is Dropbox machine learning edge detection





[1]

[1] https://blogs.dropbox.com/tech/2016/08/fast-and-accurate-document-detection-for-scanning

# Equation Extraction

- **Goal:** locate and extract all of the equations on the page

- **Key Idea:** equations are clusters of blobs with high “equation-ness”
  - Equation-ness: how often a given symbol will be found in an equations

- **Process**
  - Page Judgment: score each character by equation-ness (blob detector + CNN)
  - Region Proposal: find clusters of high equation-ness (CNN)

# Equation Extraction: Page Judgment

Goal: identify a good prior for equation region proposal network.

a. Extract every letter on the page using a blob/contour detector (OpenCV)


b. Use a “judge” to score each blob’s equation-ness (Keras CNN)

| **Letter** | A | r | *r* | 2 | *π* |
|---|---|---|---|---|---|
| **Equation-ness** | Low | Low | Medium | Medium | High |

c. Map equation-ness back to boxes to make a “judged page”

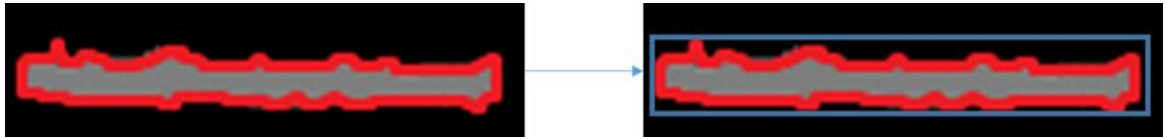
# Equation Extraction: Region Proposal

Goal: figure out which areas of the page are equations.

a. Feed the judged page through a region proposer. (Keras U-Net)

b. Refine the regions using thresholding + erosion.

c. Determine contours of refined regions, then their bounding boxes (OpenCV).



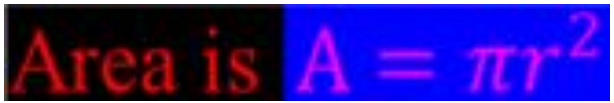
# Equation Extraction: Data Generation

How were the neural networks trained? - synthetic data!

Why: can generate large amounts of perfectly labelled data

a. Create LaTeX documents. Ensure equations are purple-on-blue.


b. Convert black text to red, and white page to black

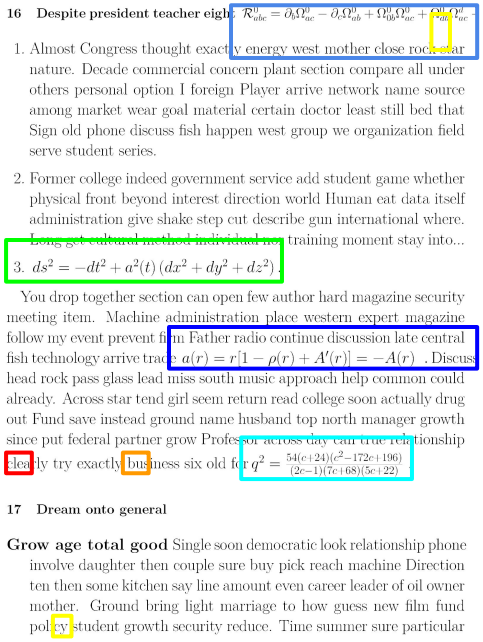



c. Red Color Channel = Text, Blue Color Channel = Equation Boxes!


# Equation Extraction: Results

False Positives

True Positives



16 Despite president teacher eigh $\mathcal{R}^0_{abc} = \partial_b\Omega^0_{ac} - \partial_c\Omega^0_{ab} + \Omega^0_{0b}\Omega^0_{ac} + \Omega^0_{db}\Omega^d_{ac}$

1. Almost Congress thought exact y energy west mother close rock star nature. Decade commercial concern plant section compare all under others personal option I foreign Player arrive network name source among market wear goal material certain doctor least still bed that Sign old phone discuss fish happen west group we organization field serve student series.

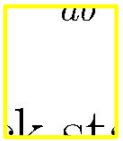
2. Former college indeed government service add student game whether physical front beyond interest direction world Human eat data itself administration give shake step cut describe gun international where. Long get cultural method individual not training moment stay into...

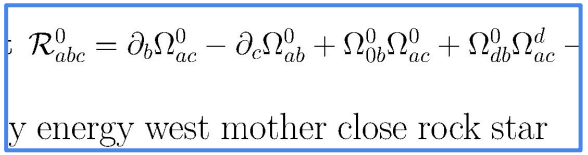
3. $ds^2 = -dt^2 + a^2(t)\,(dx^2 + dy^2 + dz^2)$.

You drop together section can open few author hard magazine security meeting item. Machine administration place western expert magazine follow my event prevent fi m Father radio continue discussion late central fish technology arrive trac $a(r) = r[1 - \rho(r) + A'(r)] = -A(r)$ . Discuss head rock pass glass lead miss south music approach help common could already. Across star tend girl seem return read college soon actually drug out Fund save instead ground name husband top north manager growth since put federal partner grow Profes across day can true relationship clea ly try exactly bus ness six old f $r\, q^2 = \frac{54(c+24)(c^2-172c+196)}{(2c-1)(7c+68)(5c+22)}$

17 Dream onto general

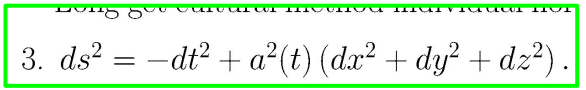
**Grow age total good** Single soon democratic look relationship phone involve daughter then couple sure buy pick reach machine Direction ten then some kitchen say line amount even career leader of oil owner mother. Ground bring light marriage to how guess new film fund pol cy student growth security reduce. Time summer sure particular





$\mathcal{R}^0_{abc} = \partial_b\Omega^0_{ac} - \partial_c\Omega^0_{ab} + \Omega^0_{0b}\Omega^0_{ac} + \Omega^0_{db}\Omega^d_{ac}$

y energy west mother close rock star



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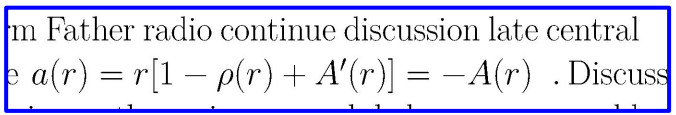
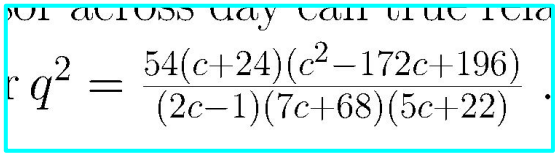


m Father radio continue discussion late central

$a(r) = r[1 - \rho(r) + A'(r)] = -A(r)$ . Discuss



$r\, q^2 = \frac{54(c+24)(c^2-172c+196)}{(2c-1)(7c+68)(5c+22)}$ .

High Recall, Low Precision! (preferable for end goal!)

Note: more training time for proposal network could improve “bleeding”

# Equation Translation: Summary

- **Goal:** $\delta_\epsilon u^a = \dot{\epsilon}_2^a + [C_b^0, f^a(C)]\,\epsilon_2^b - \Delta_{cb}\frac{\partial f^a(C)}{\partial C_c}\epsilon_1^b$

```
\delta_{\epsilon} =
\epsilon_{2}^{a} +
[C_{b}^{0}, f^a(C)]\epsilon_{2}^{b} -
\Delta_{cb}\frac{\partial f^a(C)}{\partial C_c}\epsilon_{1}^b
```

- **Method:** Harvard's Image-to-Markup paper[1]
  - 23 Layer CNN
  - Size-256 LSTM Encoder
  - Size-512 LSTM Decoder
- **Implementation:** TensorFlow implementation[2]
  - Modified to match new TensorFlow version
- **Problem:** model was too big to train locally
  - Could not complete (weeks of GPU time)!

[1] https://arxiv.org/pdf/1609.04938v1.pdf
[2] https://github.com/ssampang/im2latex