Fully Convolutional Neural Networks for Page Segmentation

Seth Stewart, BYU



Overview

1. What is Page Segmentation?

- 2. Neural Network Architectures for Page Segmentation
 - a. (How to build your own Neural Network for a Document Pixel Labeling task)
- 3. Handling overlapping content in document images
- 4. A natural extension to OCR
- 5. Challenges and Frontiers

Page Segmentation

The novel that launched the Beats, the hippies and designer jeans turns 50. But this legendary 'jovride' s actually the saddest book you'll ever read-even with God on every page. Time for another look.

KIILES BY DAVID GATES ACK KEROUAC'S "ON THE ROAD" GETS THE FULL 50TH

anniversary treatment next month, and both cheerleaders and hand-wringers acknowledge that it radically changed American culture-somehow or other. True, the National Quiet Desperation Index has only risen since 1957, and if the book's exaltation of junker

ars and diner food had really taken hold, we'd have fews er SUVs and fast-food franchises. But "On the Road" showed, and continues to show, generations of young readers a more intense, more passionate and more

dosely examined-life Some who've bust- America's archetypal ed out to live it themselves died on the treets. Others have refreshed the Ameri-be the saddest novel an seachility in music, art fash on, or in you'll ever read. If imply learning to kick tack and take pleasure in pleasure. This book has stayed. "On the Roac" car as one of its early readers would say, forev- be a liberating, life changing blast of

Net when the novel-which might now energy. But its brief be called "creative nonfiction"-appeared vawys of pure joy ts events were already 10 years in the past. and pleasure simand in 1947, when Kerouae (Sal Paradise ply add piquancy in the book) hit the road, the America that to the general am obsessed him was already dwindling. Even entation. Near the bebop-apparenty the only worthwhile product of nodemity-was in decline, from an apparition with once described him-Charlis Parker hot to West Coast cool, Ker- long white hair self and Cassady as uac mostly loved the vestiges of the Great (maybe a vision) Catholic auddies epression of the '30s: the hobis, hitch- maybe a crize ikers, migrant workers and good plain wanderer) gives Sal the Word: "Go moati came the heart of "On the Road." Neal Cast folks just trying to get by. "In those days," a for man." He didn't say Gomun go nowbey tells Sal. "you'd see hurdreds of men riding's flattar ... all kinds of men out 50th anniversary nonsense. What near, the of work and going from one place to anoth- 50th anniversary of the 30th anniversary came Kerouac's own falfillment and nemeer and some of them just wandering ... marketing ploy? But I have to admit that, sis the doppelganger who faally ahan. Brakenen never used to bother you in those thanks entirely to the publishing industry. bet, in both senses.

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lisher, has issued a "50th Anniversary Fabl tion " which made not like the edition way could've bought on the 49th anniversary. except for its reproduction of Gilbert Mil stein's prescient review in The New York Times of Sept. 5, 1957. Millstein called the nevel's publication "an historic occasion"back then, such an assertion in the Eaper of Record guaranteed it would be prescientand saw that the book was a search for "affirmation" and "belef" On the other hand neocon-to-be Norman Fodhoretz wrote in Partisan Review that the implicit message of"On the Read" was "Kill the intellectuals who can talk cohorently, kill the people who can sit sill for five minutes at a time. kill those incomprehensible characters who are capable of getting seriously involved with a woman, a job, a cause," (Was he smoking "tea"?) Over the years Podhoretz has probably dore mere far Keromac's carser than Milstein The Library of America will observe the

anniversary with a volume of five "road noveb": "On the Road" "The Dharma Bums," "The Subterraneans," "Tristessa" an "Lonesome Traveler," as well as a selection of journal entries. (But not the power ful, terrifyingly depressing "Big Sur," compared with which "On the Road" i a jovride.) Civi

Lights Books, the criginal publishe of Allen Ginsberg's "Howl"-which had or 50th anniversar last year-is putting posthumous memoir - Edia Kossuna Dash er, who served a brief wife--his "life's wife," he taid. As usual with his rives, she got time off or good behavior Kerouac-Parker never got over "the fulfilmen and nemesis of my south SIDE BY SIDE The

and she kept memories of the young man who liked to make love in the moming and carried a comb for ha powfick-"it was the scourge of his vanity, She also had a froat-row seat for the predews of the Sal-and-Dean show, which h sady, Dean Moriarty in the nevel, was the ays. I dont know about teday." Paradise st. is both senses. On the Road" once again has my total attention. Viking the book's orginal pub-But Viking has the real goods-not nast

AUGUST 12. 2007 NEWSWEEK 51



ICDAR 2011

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ICDAR 2015 http://www.primaresearch.org/RDCL2015/

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ICDAR 2009 http://www.cse.salford.ac.uk/prima/ICDAR2009 pscomp/

http://www.primaresearch.org/ICDAR2011 competition/

Page Segmentation

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Superpixel & Pixel Labeling

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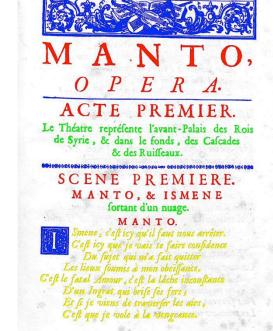
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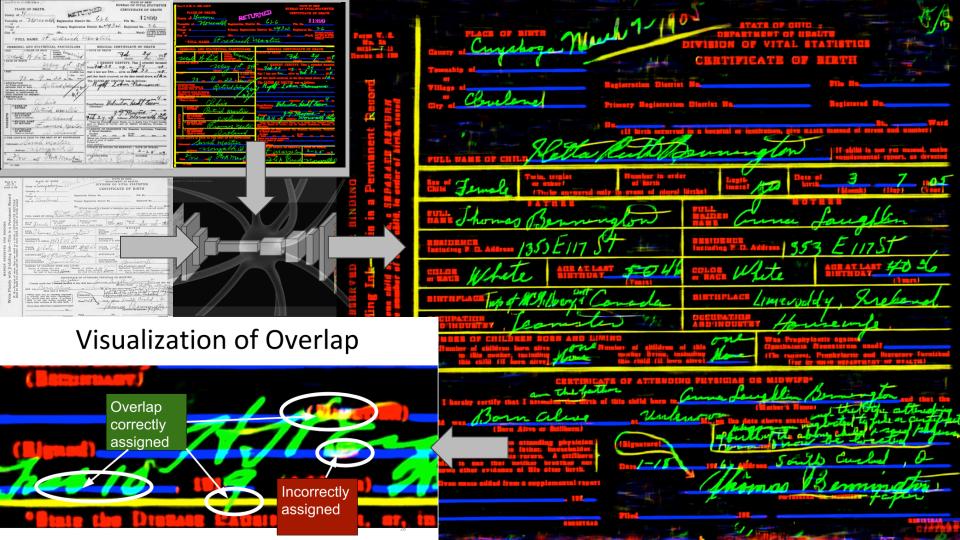
Maroua Mehri, Pierre Héroux, Petra Gomez-Krämer, and Rémy Mullot. 2017. Texture feature benchmarking and evaluation for historical document image analysis. Int. J. Doc. Anal. Recognit. 20, 1 (March 2017), 1-35. DOI: https://doi.org/10.1007/s10032-016-0278-y

Maroua Mehri, Pierre Héroux, Rémy Mullot, Jean-Philippe Moreux, Bertrand Coüasnon, and Bill Barrett. 2017. Historical Book Analysis Competition, Organization website, http://icdar2017hba.litislab.eu/index.php/dataset/, Accessed 9 Oct 2017,

Pixels in the Wild Form V. S. No. 11-50M-8-20-17 . STATE OF OHIO 1 billion images @ 12 MP each = BUREAU OF VITAL STATISTICS PLACE OF DEATH. CERTIFICATE OF DEATH 12x10¹⁶ pixels (**12 Petapixels**) County of 11899Mounter Registration District No Township of. STATE OF OHIO areau of Vital Statistic or Primary Registration District No. 4934 Registered No. 26 Village of [lf death occurred in a hospital or institu-tion, give its NAME instead of street and OF City of. Ward) 841 redrick Board of Health File No. ² FULL NAME STATE OF UTAH-DEATH CERTIFICATE Illean aleatur Ann Sharp PERSONAL AND STATISTICAL PARTICULARS MEDICAL CERTIFICATE OF DEATH THTS I 3 SEX COLOR OR RACE 16 DATE OF DEATH 5 SINGLE and } in orde un Shan NARRIED Was WIDOWED OR DIVORCED (Write the word) , 191.9. (Year) DICAL CERTIFICATE OF DEAT ma (Month) 6 DATE OF BIRTH I HEREBY CERTIFY. That I attended deceased 82.3 1912 COLOR OR RACE (Month) (Year) 1919 7 AGE If LESS than BIRTHPLACE that I last saw here ottawo chi 1 day,..... ...hrs. and that death occurred, on the date stated above, at A.m. OCCUPATI min. The CAUSE OF DEATH* was as follows: 8 OCCUPATION Noah (a) Trade, profession, or particular kind of work ired date (b) General nature of industry, business, or establishment in which employed (or employer) IRTHPLACE 12 MAID State or country) 17-1015 THE CITT OF NEW YORK. No, of Certificate and 13BIRT STATE OF NEW YORK. DEPARTMENT OF HEALTH. Contributory 10 NAME OF FATHER CERTIFICATE AND RECORD OF MARRIAGE (SECONDARY 0025 Seter Jopovick Parascevia Roscorta 11 BIRTHPLACE OF FATHER (State or country) (Signed morre the 235 moore the 2 MAIDEN NAME *State the DISRASE CAUSING DEATH, or, in deaths from VIOLENT CAUSES, state (1) MEANS OF INJURY; and (2) whether ACCEDENTAL, SUICIDAL, or HOMICIDAL. 23 OF MOTHER Nh.t. vite. 18 LENGTH OF RESIDENCE (For Hospitals, Institutions, Transients 13 BIRTHPLACE Ainila OF MOTHER or Recent Residents) State or country At place In the motorman & to Maiden Name Decupatio 0 of death. .ds. State HE ABOVE IS TRUE TO THE Where was disease contracted, 7 mitris Birthplac anotre. Birthalac If not at place of death? Former or Father's Name resm formant). usual residence 19 PLACE OF BURIAL OR REMOVAL DATE OF BURIAL Shevchur. ba (Address). 2/24 ADDRESS 20 UNDERTAKER I hereby dertify that the above-named g Marriage by me, in accordance with the Laws of the State of New York. Street), in the made 11-3184 Whed. Vato. Miron Korcell 1919 Ohio Death Record 6 Honoland Diduck

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Ground-Truthing

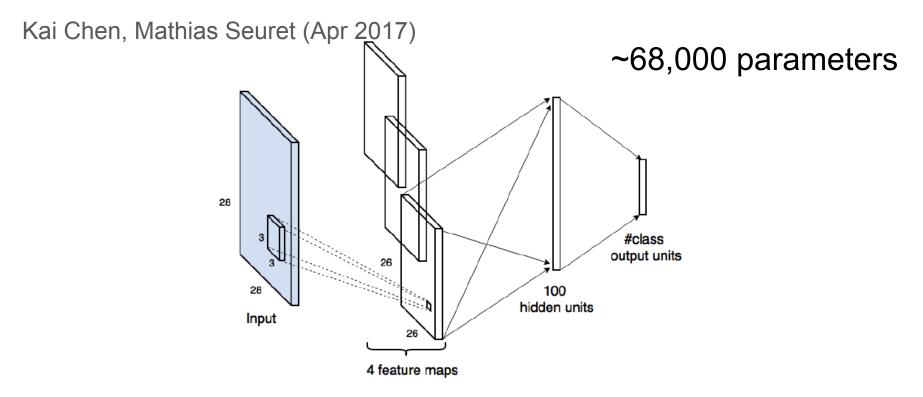
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Architectures

By Lorie Shaull (Own work) [CC BY-SA 4.0 (https://creativecommons.org/licenses/by-sa/4.0)], via Wikimedia Commons

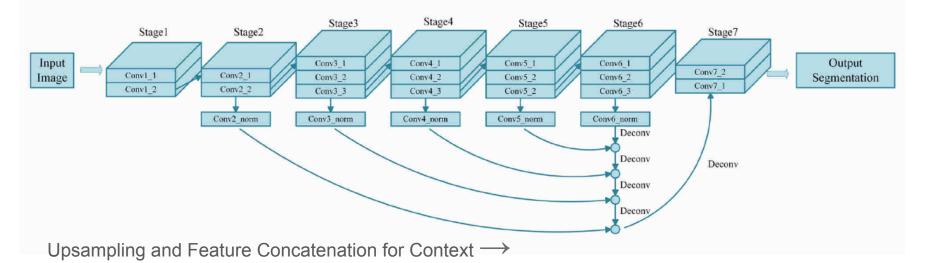
Convolutional Neural Networks for Page Segmentation of Historical Document Images



Winners of the ICDAR2017 Competition on Layout Analysis for Challenging Medieval Manuscripts

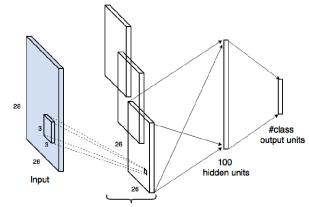
Based on VGG-16

~138 Million parameters!

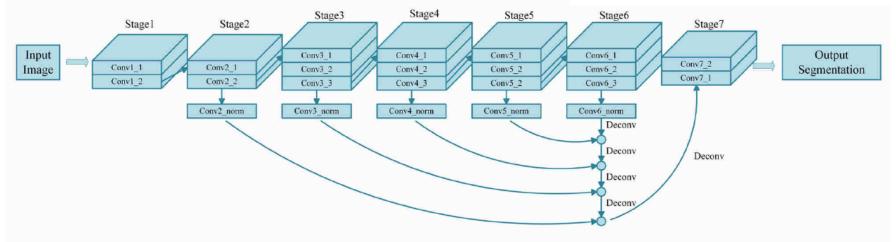


Which way to go?

138M vs 68K: 2000x difference in # of parameters







We're caught in a net

DenseNets

https://arxiv.org/abs/1608.06993

ResNets https://arxiv.org/abs/1611.08323

SqueezeNets https://arxiv.org/abs/1711.05491

ShuffleNets

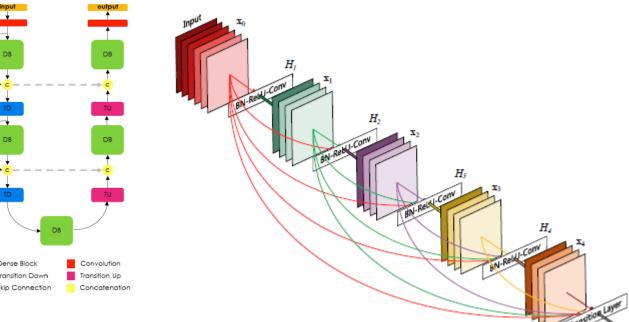
InceptionNets

XceptionNets

Densely Connected Convolutional Networks

The One Hundred Layers Tiramisu: Fully Convolutional DenseNets for Semantic Segmentation

<u>Layers: Params</u> 56: 1.5M, 67: 3.5M, 103: 10M



10x Reduction!

https://arxiv.org/abs/1611.09326

https://arxiv.org/abs/1608.06993

Historical Book Analysis Competition

Two competitors,

One neural and one not.

Neural method outperformed

Non-neural by

4.79% Weighted F-Measure

11 Books,

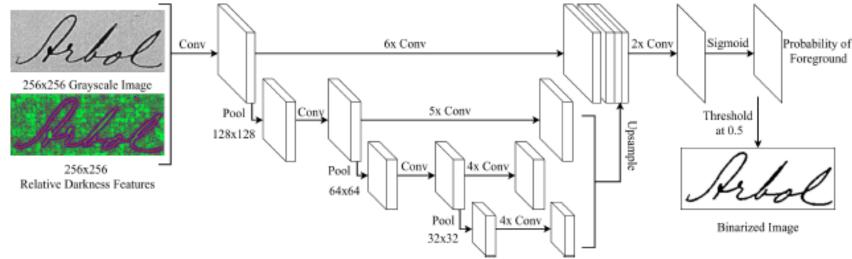
61-98% WFM per book

https://dl.acm.org/citation.cfm?id=3151528





Multi-Scale network architecture



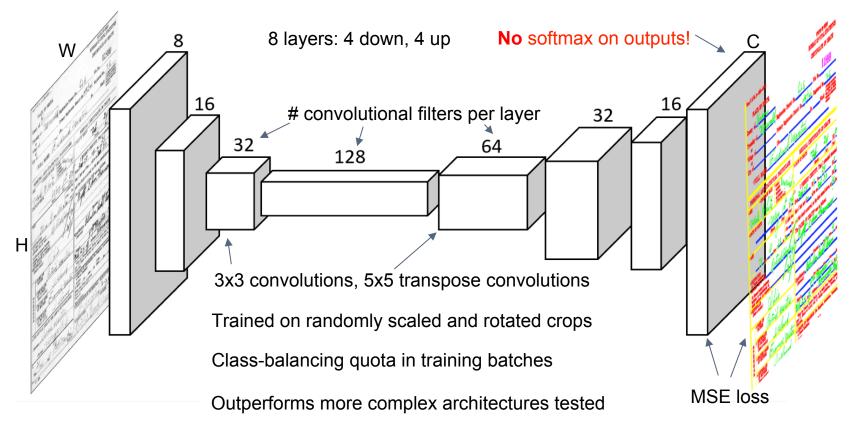
Document Image Binarization with Fully Convolutional Neural Networks

Chris Tensmeyer, Tony Martinez https://arxiv.org/abs/1708.03276

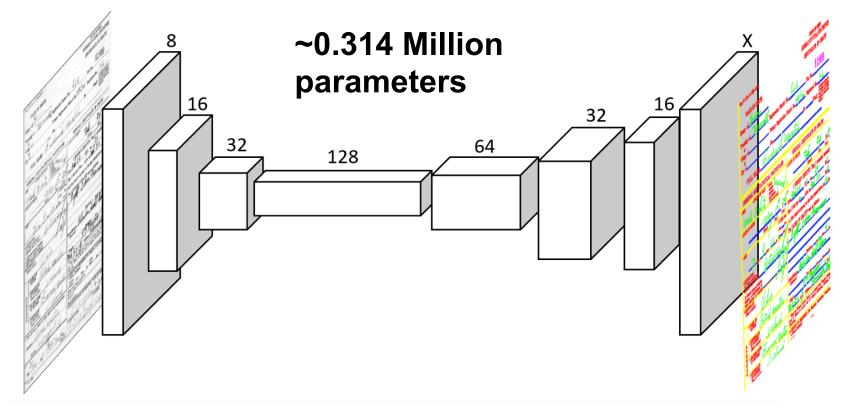
Back to Form Images Form V. S. No. 11-50M-8-20-17 STATE OF OHI BUREAU OF VITAL STATISTICS PLACE OF DEATH. CERTIFICATE OF DEATH County of 11899 **Registration District N** Township of. File No. or Primary Registration District No. 49 26 Village of Registered No. [If death occurred in a hospital or institu-tion, give its NAME instead of street and OF City of Ward) ² FULL NAME. PERSONAL AND STATISTICAL PARTICULARS MEDICAL CERTIFICATE OF DEATH SINGLE Married SEX 4 COLOR OR RACE 16 DATE OF DEATH WIDOWED OR DIVORCED (Write the word) 191.9 lall u (Month) (Year) 6 DATE OF BIRTH I HEREBY CERTIFY, That I attended deceased May 10 from T.M 1912 (Month) (Year) 1919 7 AGE If LESS than that I last saw here l day,... and that death occurred, on the date stated above, at 1.A.m. ...hrs. 10 ...min. mos CAUSE OF DEATH* was as follows: 8 OCCUPATION doas. (a) Trade, profession, or particular kind of work. (b) General nature of industry, business, or establishment in which employed (or employer BIRTHPLACE (State or country) no Contributory 10 NAME OF (SECONDARY FATHER 11 BIRTHPLACE OF FATHER PARENTS (Signed) (State or country) 1/4 (Address) 12 MAIDEN NAME OF MOTHER *State the DISEASE AUSING DEATH, or, in deaths from VIOLENT CAUSES, state (1) MEANS OF INJURY; and (2) whether ACCIDENTAL, SUICIDAL, or HOMICIDAL. 18 LENGTH OF RESIDENCE (For Hospitals, Institutions, Transients, or Recent Residents) 13 BIRTHPLACE OF MOTHER (State or country) At place In the of deathds. State. KNOWLEDGE 14 THE ABOVE IS TRUE TO THE BEST Where was disease contracted, If not at place of death?...... Former or (Informant). usual residence. 19 PLACE OF BURIAL OR REMOVAL | DATE OF BURIAL (Address) aryo (en. 20 UNDERTAKER ADDRESS u Filed ... Made Registrar our. 11-3184

1919 Ohio Death Record

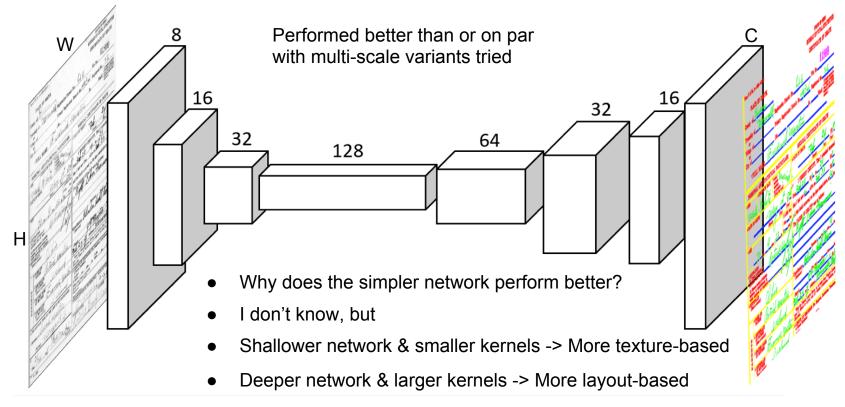
Convolutional Neural Network Architecture



Convolutional Neural Network Architecture



Convolutional Neural Network Architecture



• Smaller architecture -> Fewer parameters -> Less ability to overfit

Architecture Takeaways

- 1. Think about the target variables: Do I want Long-term context (logical layout) or local/textural analysis (graphical layout)?
 - a. Smaller context can be better for textural, and larger context may be needed for logical, high-level labelings.
- 2. Document images are very high resolution. Prepare for high throughput.
- 3. Loss function matters -- you get what you optimize for
- 4. Training balancing: Include more of what you are worse at, within reason

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11-3184

23

Masking Content Channels Input * Mask + (255 * 1-Mask) = Masked Image

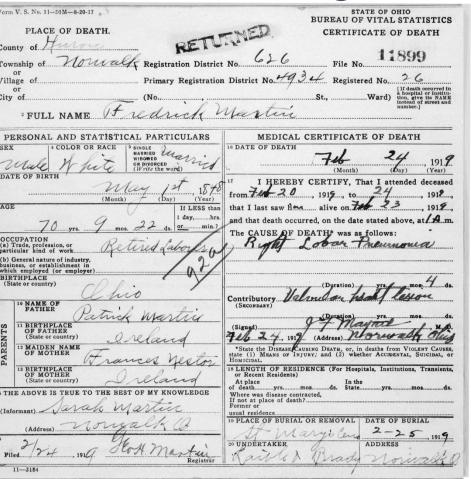
Form	V. S. No. 11-50M-8-20-17	STATE OF OHIO BUREAU OF VITAL STATISTICS
	PLACE OF DEATH.	CERTIFICATE OF DEATH
	L/	CERTIFICATE OF DEATH
Cour	nty of Africante	1., 11000
	nship of Mounally Registration District	
Villa	age of Primary Registration	n District No. 49.3.44 Registered No. 2-6
City	of	
	"FULL NAME If redrick	Martine same.)
PE	ERSONAL AND STATISTICAL PARTICULARS	MEDICAL CERTIFICATE OF DEATH
3 SEX	+ COLOR OR RACE	16 DATE OF DEATH
2	dale It hit " monto harried	Hanth) (Marth) (Var)
6 DAT	TE OF BIRTH	IT I HEREBY CERTIFY, That I attended deceased
	May 125 1878	7.1 24 . 24 .
	(Month) / (Day) (Year)	from 7.47 20, 1919, to 7, 1917, 1917,
TAGE	If LESS than I day, hrs.	that I last saw firm alive on The 23, 1912,
	70 - 9 - 22 4 or min?	and that death occurred, on the date stated above, at
	UPATION OF TAX	The CAUSE OF DEATH was as follows:
(a) 7	Trade, profession, or Retired daborers	1. Right Lovar Theumonia
(h) (General nature of industry	
busin	ness, or establishment in h employed (or employer)	
BIR	THPLACE ate or country)	(Duration) + and and 4 to
	(his	- Hole has the to taway
100	FATHER D	(SECONDARY)
	Patrick Masting	(Duration) yrs mos ds.
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LN	(State or country) Ireland	716 24. 1919 (Address) Mores alty Oling
PARENTS	12 MAIDEN NAME OF MOTHER	*State the DISEASE AUSING DEATH, or, in deaths from VIOLENT CAUSES, state (1) MEANS OF INJURY; and (2) whether ACCIDENTAL, SUICIDAL, or
PA	Trances yestor	HOMICIDAL
	IS BIRTNPLACE	18 LENGTH OF RESIDENCE (For Hospitals, Institutions, Transients, or Recent Residents)
1	(State or country)	At place In the of death yrs. mos ds. State yrs. mos ds.
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(Inte		usual residence
	(Address) Norgant Co	++
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	11-3184	1

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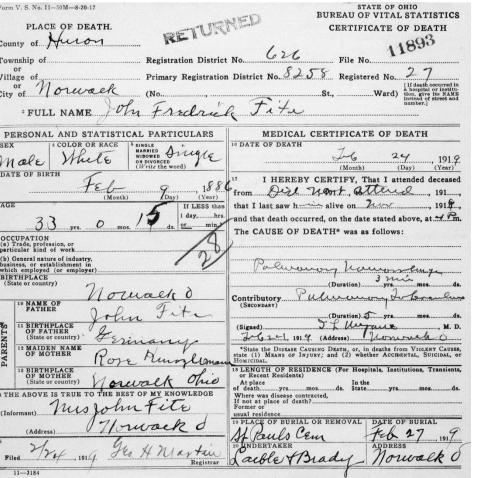
Results

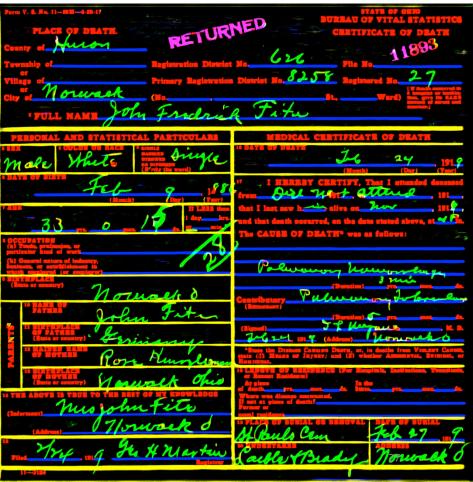
Single Training Image





Same Writers



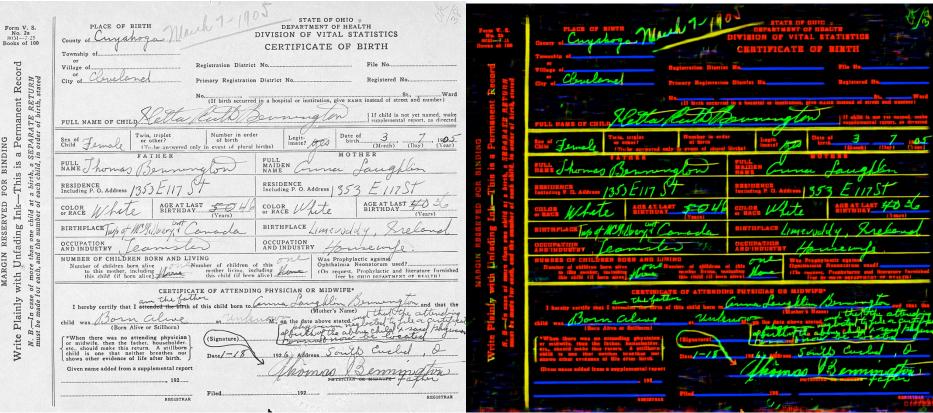


Different Writers

orm V. S. No. 11-150M-8-4-15		BUREAU OF VITAL STATISTICS
PLACE OF DEATH.	KETU	CERTIFICATE OF DEATH
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FULL NAME MOO		over number.]
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PERSONAL AND STATISTIC	AL PARTICULARS	MEDICAL CERTIFICATE OF DEATH
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male white	OR DIVORCEL	Jet. 9 , 1918
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VIS. mos.	ds. or	and that death occurred, on the date stated above, are m.
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hich employed (or employer)		
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		Contributory.
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Different Form Types



1905 Ohio Birth Certificate

BINDING

FOR

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MARGIN

Different Form Types

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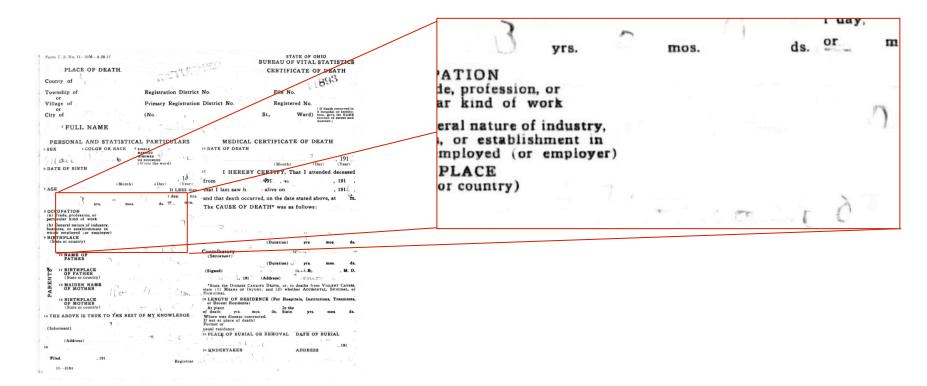


¹⁹⁰⁰ U.S. Census

Handwriting Channel

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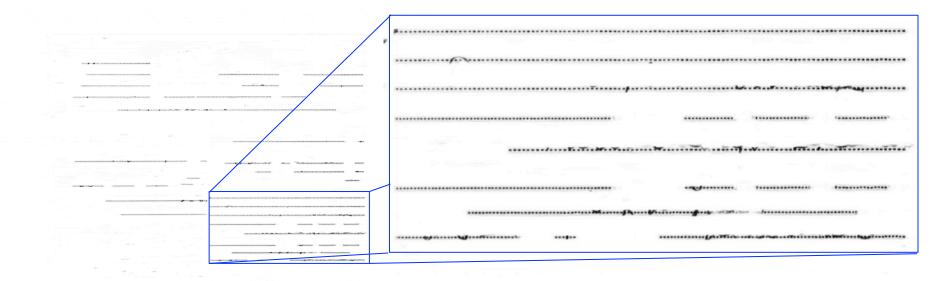
Machine Print Channel



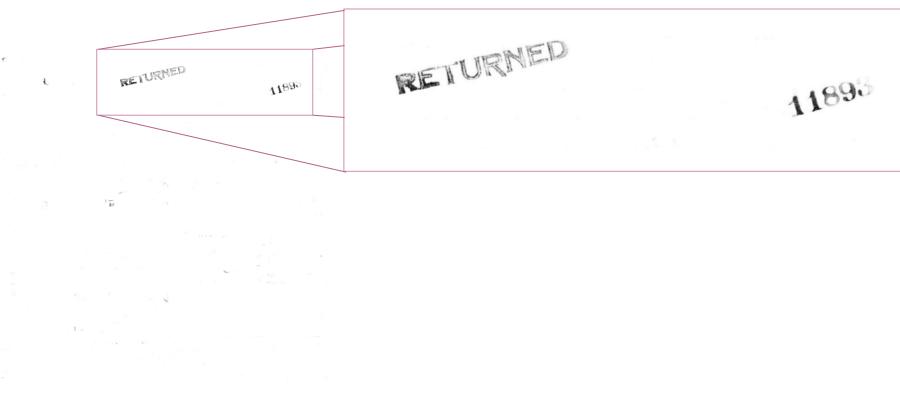
Solid Lines Channel



Dotted Lines Channel



Stamp/Decoration Channel



Open Problems

Have We Forgotten about Geometry in Computer Vision?

https://alexgkendall.com/computer_vision/have_we_forgotten_about_geometry_in_computer_vision/



Alex Kendall

Computer Vision & Robotics Researcher

Deep learning has revolutionised computer vision. Today, there are not many problems where the best performing solution is not based on an end-to-end deep learning model. In particular, convolutional neural networks are popular as they tend to work fairly well out of the box. However, these models are largely big black-boxes. There are a lot of things we don't understand about them.

Dense Layers

https://www.google.com/search?safe=active&biw=1366&bih=633&tbm=isch&sa=1&ei=V2WMWovJF-PX0gKZ1azIAQ&q=dense+cake+recipe+site %3Awikimedia.org&oq=dense+cake+recipe+site%3Awikimedia.org&gs_l=psy-ab.3...9304.12238.0.12375.19.16.0.0.0.0.223.1716.3j7j2.12.0...0...1c. 1.64.psy-ab..7.1.125...0i30k1j0i8i30k1j0i24k1.0.v5TK6hZEBi4

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Where to Go from Here

Marriage of Computer Vision and Deep Learning

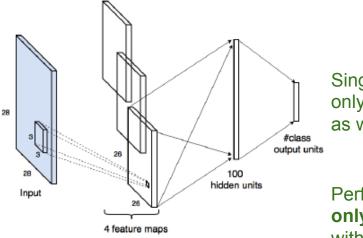
Resource-Efficient Processing (ms/image)

Document Image Page Segmentation and Character Recognition as Semantic Segmentation

Seth Stewart and Bill Barrett Brigham Young University stewart.seth.a@gmail.com



Chen and Seuret CNN for Page Segmentation



Single convolutional layer with only 4 feature maps performs as well as more layers/maps

Performs ~99% as well with **only 2 training images** as with many more

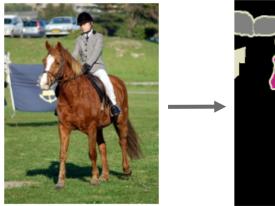
Single-Layer Convolutional Neural Network for page segmentation by Chen and Seuret

K. Chen and M. Seuret. 2017. Convolutional Neural Networks for Page Segmentation of Historical Document Images. ArXiv e-prints (April 2017). arXiv:cs.CV/1704.01474



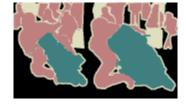
Semantic Segmentation

Pixel-wise labeling of images









M. Everingham, L. Van Gool, C. K. Williams, J. Winn, and A. Zisserman. The pascal visual object classes (voc) challenge. IJCV, 88(2):303–338, 2010

Semantic Segmentation Convolutional Neural Network Architectures

[Noh, et al. 2015]

Fully Convolutional Network [Long and Shelhamer, 2014]

Learned upsampling allows for denser predictions given modest additional computation forward/inference ixelvise backward/learning Convolution network Deconvolution network 384 256 4096 4096 21

H. Noh, S. Hong, and B. Han, "Learning deconvolution network for semantic segmentation," in The IEEE International Conference on Computer Vision (ICCV), December 2015

Downsampling-upsampling Network

Fully Convolutional Models for Semantic Segmentation. Evan Shelhamer,

The Problem

Many documents have heterogeneous content consisting of

- handwriting
- machine print
- solid lines
- dashed lines
- stamps

that are

- interleaved

and frequently

- overlap

ſ	Form V. S. No. 11-50M-8-20-17	STATE OF OHIO BUREAU OF VITAL STATISTICS
	PLACE OF DEATH	CERTIFICATE OF DEATH
	County of Annora	. 626 11899
	Township of Mountary Registration District	No
	Village of Primary Registration	a District No. 4934 Registered No. 26
	City of	
	* FULL NAME If redrick	Martin number.]
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	(b) General nature of industry, business, or establishment in	
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	PATHER Patrick magnitic	(SECONDARY) (Dutation) yrs. mos. ds.
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	14 THE ABOVE IS TRUE TO THE BEST OF MY KNOWLEDGE	At place In the of death yrsmosds. Stateyrsmosds. Where was disease contracted,
	(Informant), Jarah Martin	If not at place of death? Former or usual residence
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10 H-1915 THE CITY OF NEW YORK. No, of Certificater STATE OF NEW YORK. DEPARTMENT OF HEALTH. CERTIFICATE AND RECORD OF MARRIAGE (Bride) Cler To kovick arasecura Maracka 31 moore the Bride's Residence Age Color Le 100 -Single, Widowed or Diverced Maiden Name, ntrio Birthplace Father's Name Mother's Shevchuk? Maiden Name Number of Bride's Marriage pom and bride were joined in Marriage by me, in accordance with Mos Thors M. J. A (Street.) in the (Street), in the City of New York, this. Par. Worked. Vato. Signature of person performing the Ceremony Miron Korcers. Official Station. Witnesses Konstant Diduce to the Marriage Residence

45

10 H-1915 THE CITY OF NEW YORK. No, of Certificater STATE OF NEW YORK. DEPARTMENT OF HEALTH. CERTIFICATE AND RECORD OF MARRIAGE (Bride) Cler To kovick arasecuia Maracka 31 moore the Bride's Residence Age Color Le 100 ----Single, Widowed or Divorced Maiden Name, if a Widow Handwriting Removed Intrio Birthplace Father's Name facob Shevehurz Mother's Maiden Name Number of Bride's Marriage oom and bride were joined in Marriage by me, in accordance with Mos Thors M. J. A (Street.) in the ation) the Laws of the State of New York, at_ Borough of North C (Church), in the City of New York, this. Par. Weled. Vator Signature of person performing the Ceremony Miron Korcers. Official Station Witnesses Konstant Didner to the Marriage Residence

46

We use a Convolutional Neural Network to Semantically label each document component at the pixel level

Perm V. S. Ra. 11-110-1-101-15 PLACE OF DEATH.	BUREAU OF VITAL STATISTICS CERTIFICATE OF DEATH
County of Huron, Township of Monurally Registration District	t No. 626 Pile No. 11899
Village of Primary Registratio or City of No.	a District No. 4994 Registered No. 26 St., Ward) Ward and a start of the start of t
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14 THE ABOVE IS TRUE TO THE BEST OF MY KNOWLEDGE	or accent Automaty) At place yra, de. Biste yra, mag, de. Where was disease contracted, If not at place of desth?
(Informant) Sarah Martin (Advan) - Norwalk (a	Pormer or usual residence
18 2/ r.t . 189 Hort Martin	H- Maryolan 2-25 189
Piled Pit , IN Balding	Raible A Brady Normalk

...allowing each component to be peeled off into a separate layer and processed selectively

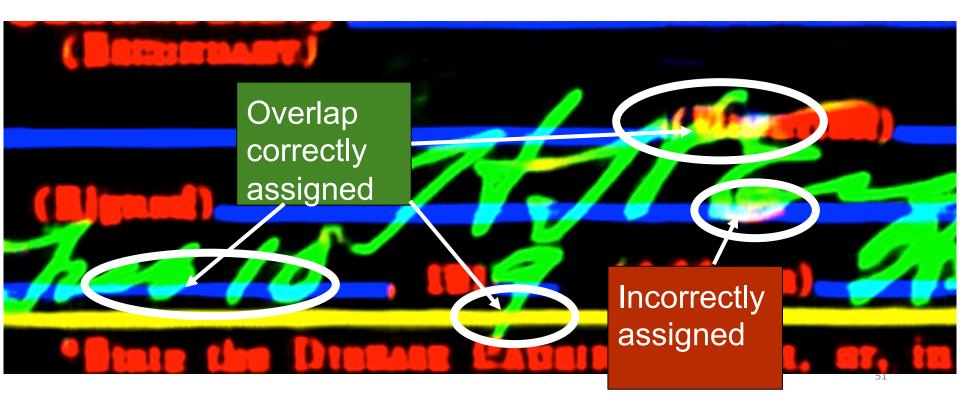
Farm V. S. No. 11-0086-9-08-13	STATE OF ORIO BUREAU OF VITAL STATISTICS
PLACE OF DEATH.	CERTIFICATE OF DEATH
County of Hurrow	
Township of Mourally Registration Distric	t No. 626 File No. 1899
Village of Primary Registratio	n District No. 4994 Registered No. 26
City of (No	St., Ward) and St.
"FULL NAME If redrick	Bt. Ward) Ward &
PERSONAL AND STATISTICAL PARTICULARS	
	16 DATE OF DEATH
Male A fit and with war	IN DATE OF DEATH IN DATE OF DEATH (Menth) (Year) II HEREBY CERTIFY. That I attended deceased
DATE OF BIETE May 1st, 1540	I HEREBY CERTIFY, That I attended deceased from 14-2., 191_, to 24, 191_, 191_,
(Menth) (Day) (Year)	from 744 - 2 , 1915 , to, 1915 , to, 1915 ,
TAGE (Head) (Par) TAGE (Head) (Par) TAGE (Head) (H	that I last saw have alive on 700
<u>70_m7 not 22 ds emay</u>	The CAUSE OF DEATH ^a was as follows:
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(State or country)	(Dentin) (
(Jule or country)	Contributory Valunda, July Levan
Patrick master	
(and a country) Oreland	(Bigned) 7 Maar Karlow 146 24, 187 (Addrew) 107 1047 2047 2047 19tas the Distance Common Darry, or, is doubt from Vincent Common ebit (1) Maass or Injury; and (2) whether Accemertal, Birtenak, or Beauchas,
13 NADEW RAW	*State the Distate Course Diars, or, in deaths from Visigury Course,
Frances yestor	state (1) MEANS OF INJURY; and (2) whether ACCEMENTAL, SUICIDAL, or HOMICIDAL
(State or country) Orland	HOMICINA. 18 LENGTH OF RESIDENCE (For Hospitals, Institutions, Transients, or Recent Residents) At place In the
14 THE ABOVE IS TRUE TO THE BEST OF MY ENOWLEDGE	At place . In the
(Internet) Sarah Martin	
(Adress) - Norgalk (Q	TO PLACE OF EVELAL OF REMOVAL DATE OF EVELAL
" 2/24 , 10 Stort martin	Aure & Brady Normalt 6
	Raible K Brady Norwalke
113184	
19	19 Ohio Death Record

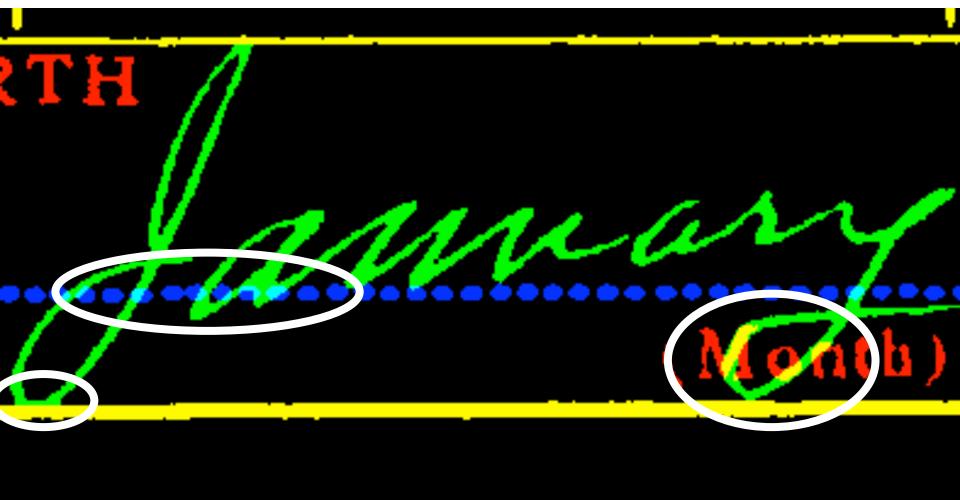
Methods

Overview

- 1. What is Page Segmentation?
- 2. Neural Network Architectures for Page Segmentation
 - a. (How to build your own Neural Network for a Document Pixel Labeling task)
- 3. Handling overlapping content in document images
- 4. A natural extension to OCR
- 5. Challenges and Frontiers

Visualization of Overlap





Two-form cross-validation

STATE OF OHIO Form V. S. No. 11-50M-8-20-17 BUREAU OF VITAL STATISTICS PLACE OF DEATH. CERTIFICATE OF DEATH County of. 11899 Mounally Registration District N Township of File No. or Primary Registration District No. 49 26 34 Registered No .. Village of [If death occurred in a hospital or institu-tion, give its NAME instead of street and 01 City of Ward) Martin ² FULL NAME. PERSONAL AND STATISTICAL PARTICULARS MEDICAL CERTIFICATE OF DEATH + COLOR OR RACE 16 DATE OF DEATH SEX 5 SINGLE WIDOWED CHERNING 716 1919 hit Male (Month) (Year) & DATE OF BIRTH I HEREBY CERTIFY. That I attended deceased from ter 20 1912 (Month) (Year) that I last saw here 1919 If LESS than hrs 1 day and that death occurred, on the date stated above. at 1.4. m. was as s OCCUPATION (a) Trade, profession, or particular kind of work. used dal (b) General nature of industry, business, or establishment in which employed (or employe 9 BIRTHPLACE (State or country) tard Contributory Uglas NAME OF (SECONDAR ¹ BIRTHPLACE OF FATHER (State or country) PARENTS lan MAIDEN NAME OF MOTHER *State the DISEAS AUSING DEATH, or, in deaths from VIOLENT CAUSES, state (1) Howicip rance 18 LENGTH OF RESIDENCE (For Hospitals, Institutions, Transients. 3 BIRTHPLACE OF MOTHER (State or country) or Recent Residents Raza At place of deathds. State. VIS. mos. 14 THE ABOVE IS TRUE TO THE BEST OF MY KNOWLEDGE (Informant). usual resider 19 PLACE OF BURIAL OR REMOVAL | DATE OF BURIAL (Address) 2-25 - Maryo Cer 20 UNDERTAKER ADDRESS 124 aile à u Filed rady 11-3184

Form V. S. No. 11-50M-8-20-17			TATE OF OHIO DF VITAL STATISTICS
PLACE OF DEATH.		CERTIN	ICATE OF DEATH
County of Huron			11890
Township of	Registration District		ło
Village of or City of <i>Horusek</i> ² FULL NAME Ell	NoE.H.		(ered No
PERSONAL AND STATISTICA	L PARTICULARS	MEDICAL CERTIFICA	TE OF DEATH
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DATE OF BIRTH	11 1847	17 L HEREBY CERTIFY,	1.
(Month)	(Day) (Year) If LESS than	that I last saw here alive on	126. 17 1919,
72 0	7 de 1 day,	and that death occurred, on the da	. 6
s OCCUPATION	ds.	The CAUSE OF DEATH* was	as follows:
 (a) Trade, profession, or Accuration particular kind of work (b) General nature of industry, business, or establishment in which employed (or employer). 	wife	Permin C.	enema
BIRTHPLACE (State or country) (State or country) (State or country)		(Duration)	
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DF FATHER (State or country) NEU	Vork	(Signed) John U. S. Pub (19), 191.9 (Address)	phen, M. D.
11 BIRTHPLACE 10 FATHER (State or country) 12 MAIDEN NAME OF MOTHER Corructe	a Warney	*State the DISEASE CAUSING DEATH, or, state (1) MEANS OF INJURY; and (2) with HOMICIDAL.	in deaths from VIOLENT CAUSES, aether ACCIDENTAL, SUICIDAL, or
13 BIRTHPLACE OF MOTHER (State or country)	mont	18 LENGTH OF RESIDENCE (For Ho or Recent Residents) At place	he
14 THE ABOVE IS TRUE TO THE BEST (Informant) A 9 Miles	OF MY KNOWLEDGE	of death yrs	ds.
(Address) Nor	wack O	usual residence	DATE OF BURIAL
15 Filed 2/20, 191 9 Ke	H. martin	20 UNDERTAKER	ADDRESS Horney O.
11-3184	Registrar	a more would be	no cuotante o,

Two-form cross-validation

Form Instance A validated against Form Instance B				
Class	Training		Validation	
	Precision Recall		Precision	Recall
Machine Print	0.927	0.783	0.812	0.891
Handwriting	0.930	0.868	0.842	0.929
Solid Lines	0.815	0.912	0.574	0.996
Dotted Lines	0.857	0.923	0.735	0.927
Stamps	0.794	0.885	0.199	0.282
т · 1 г	T (D			

Trained on Form Instance B

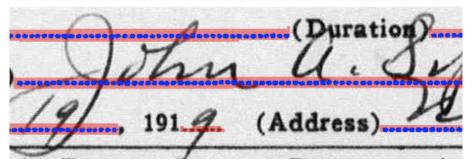
Class	Training		Validation	
	Precision	Recall	Precision	Recall
Machine Print	0.967	0.945	0.869	0.703
Handwriting	0.935	0.940	0.897	0.734
Solid Lines	0.906	0.916	0.743	0.530
Dotted Lines	0.930	0.920	0.885	0.777
Stamps	0.682	0.979	0.279	0.235

FILACE OF DEATH	BUREAU OF VITAL STATISTI CERTIFICATE OF DEATH
Township of Mountally Registration Distric	et Na. 676 File No.
or Village of Primary Registratio	on District No. 49344 Registered No. 26
or City of (No.	
	St. Ward) the first in the
· FULL NAME It redricts	manue
PERSONAL AND STATISTICAL PARTICULARS	MEDICAL CERTIFICATE OF DEATH
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	746 24 19
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(Manth) /* (Day) (Year)	from 7.60
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(b) General sature of industry,	/ /
which employed (or employed)	11
(State or country)	21 (Optim) 1. The T
MANUE OF COMMENT	Contributory Dalance an Julan f Laton
Patrick Martin	(Bratin) m. m.
2 BERTHPLACE	dingo 97 mayree 1.
& Clean or country) Ireland	716 27 mg allow Morris alty Ol
"By HOTHER (Land) Oreland	"State the Distant Armon Durin, or, is double from Yougaw Can state (1) Manua or Dayran; and (2) whether Accedurat, Southand
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(Allow Norgalty Co	Attained 2-25
" 21 96 H 2	WUNDEFAKER ADDRESS
rese Tot ma Otor Martin	Bailder Band and inte
II-JUM Bagierie	Marin Arrand Moniale

Farm V. S. No. 11-2138-4-49-17		BUREAU OF VITAL STATISTIC
PLACE OF DEATH.		CERTIFICATE OF DEATH
county of Herron		11890
Township of		No 626 File No.
Village et Morwach City et Morwach	Primary Registration (No. Clem E. H.)	District No. 8258 Registered No. 20 St. Ward Ward Million and Mill
PERSONAL AND STATIST	TOAL BARTION ARE	MEDICAL CERTIFICATE OF DEATH
I SEE I COLOR OR RACE	Dames /	IS DATE OF DEATH
Jamale White	REALED Married	1 ebruary 17 191
BATE OF BIRTH		" / L HEREBY CERTIFY, That I attended decease
feb-		trem May , 191 8, 10/ Aman 12, 1915
(Met	sth) (Day) (Year) 27 LEDS than	that I last new har alles on fed. 17 1915
	I den ben	
72	ma 7 to the may	and that death occurred, on the date stated above, at CEL The CAUSE OF DEATH* was as follows:
72 m 0 .		
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(a) Trade, prefemien, or Aro-c. (b) General nature of industry, building, or arguiteding in which mentioned in any provided in the second seco		
(a) Trade, prefemien, or Aro-c. (b) General nature of industry, building, or arguiteding in which mentioned in any provided in the second seco		
(a) Trada preference or How (b) General sature of industry. Stations, or establishment in which employed (or express) BIFTHPIACE (State or country) Chics		The CAUSE OF DEATH* was as follows: Demotions Communic (Buntin) 3 yrs we.
 (a) Trade prefemines or particular tind of work (b) General nature of industry. batters, or scriptionast in which employed (or employer) DIFFERDACE 		The CAUSE OF DEATH* was as follows: Permainers Cenemin (Burnin) 3 pr me.
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al rate information for a second seco	Hours Ew York lia Harry mout et a Harry mout et a workson et a workson et a workson et a workson	The GAUGE OF DEALTH was inflowed. Dealers and the second

The Effect of Ground Truth*

Average F-scores	GT to preds	3 GTs	С
Machine Print	0.813	0.888	
Handwriting	0.845	0.889	
Solid Lines	0.673	0.844	
Dotted Lines	0.824	0.753	
Stamps	0.244	0.933	



Conclusions:

- HW and MP transfer in the 80-90% range
- Lines are more subjective
- Stamps transfer relatively poorly
 - Needs more training data



11899

*Elisa H. Barney Smith. 2010. An analysis of binarization ground truthing. In *Proceedings of the 9th IAPR International Workshop on Document Analysis Systems* (DAS '10). ACM, New York, NY, USA, 27-34. DOI=http://dx.doi.org/10.1145/1815330.1815334

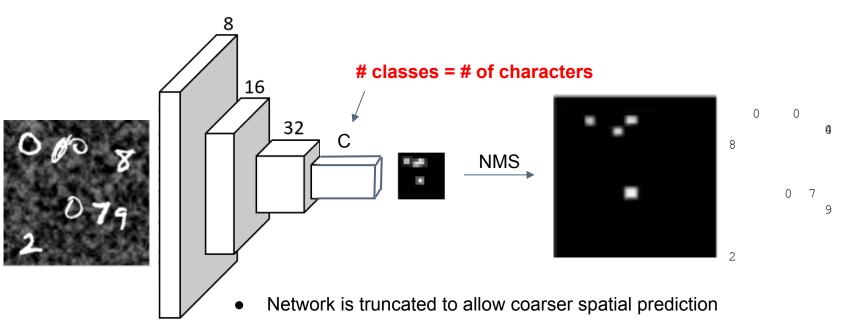
Overview

- 1. What is Page Segmentation?
- 2. Neural Network Architectures for Page Segmentation
 - a. (How to build your own Neural Network for a Document Pixel Labeling task)
- 3. Handling overlapping content in document images
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- 5. Challenges and Frontiers

What if I could tell you...

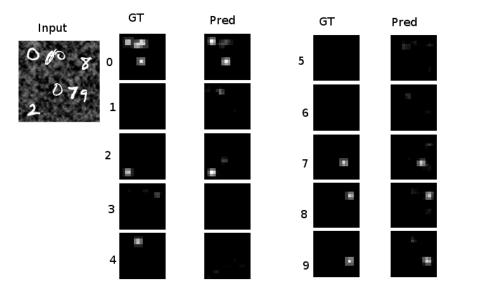
Not only is it machine print, it's a "9"

Modification for character prediction



• Threshold + Non-Maximal Suppression can be used to identify characters directly

Segmentation-free character recognizer



- Semantic Segmentation is performed to produce character heatmaps
- Easy to ground-truth
- Without tuning, a shallow network is 95% accurate at regressing MNIST digits at arbitrary locations

Segmentation-free character recognizer

Not constrained to words or lines in predetermined read order

Eliminates the need for any a priori word, character, or line segmentation algorithm.



Words, lines, and paragraphs can be recovered post-recognition

Overview

- 1. What is Page Segmentation?
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Open challenges / Future Work

-Network architecture search is still inefficient

(but maybe a small network can be good enough for some tasks?)

-Pixel labeling is still not integrated with downstream tasks (OCR, Handwriting recognition, region pairing)

-Fuse character recognition with other document processing tasks

Semantic Segmentation web demo



http://bit.ly/2tgbo2G

Acknowledgements

Special thanks to:

Lucas Pinto, Allen Liao, Zhihan Tsai, Curtis Wigington Brigham Young University

Pat Schone, Jon Morrey FamilySearch

Scott Cohen and Brian Price Adobe Research

Seth Stewart and Bill Barrett Brigham Young University <u>stewart.seth.a@gmail.com</u>



Questions?

Document Image Page Segmentation and Character Recognition as Semantic Segmentation

> Seth Stewart and Bill Barrett Brigham Young University <u>stewart.seth.a@gmail.com</u>



Future/Ongoing Work

Two-form cross-validation

Form Instance A validated against Form Instance B				
Class	Training		Validation	
	Precision	Recall	Precision	Recall
Machine Print	0.927	0.783	0.812	0.891
Handwriting	0.930	0.868	0.842	0.929
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Stamps	0.794	0.885	0.199	0.282
Trained on Forr	n Instance B			
Class	Traini	ng	Validation	
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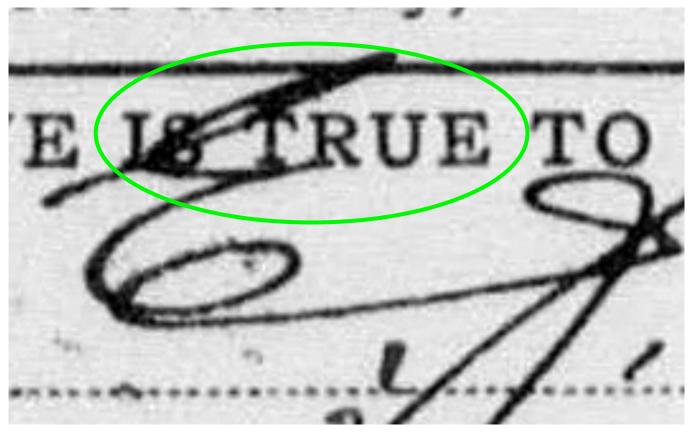
Compare to Chen and Seuret's **77-96 f.w. IU** on Parzival, Washington, and Saint Gall databases IU can be seen as symmetric precision & recall.

It is bounded as pessimistic, score-wise, relative to Prec & Rec. In other words, it will always be lower than either of these. IU is a lower bound on Prec & Rec.

But these are against arbitrary pixel-level ground truth

TODO: Compare to HBA results

Handling Class Overlap



Larger Dataset Creation

				Dox 7, 5, 75, 11-008-1017	TATE OF 0830
Parts V. 5. No. 10-1030-039417 PLACE OF DEATH. County of HULLON Tommin of Reviseration District No.	Port V S.N. 11-198-4411 PLACE OF DRATH. Contry of Acturrent Contry of Acturrent Contry of Acturrent Registration District No. 653	PARE OF DEATH PLACE OF DEATH Compt of Human Tomahi of Restauring Diaries No. 624	PERCE OF DEATH. County at Harris () RETURNED	FLACE OF DEATH Creaty at Huters, Terminity of Mountally Registration District	BURRAU OF VITAL STATISTICS CERTIFICATE OF DEATH
Village of Primary Registration District City of Norwach (No. FULL NAME Ellen E. H. Wile	Viliage of Willard Primary Registration District No. 2 Of City of No.	Village et Primary Registration District No. 8. City et Morwack (No. "FULL NAME John Fridrick Fat.	Torning at Mouth Regionation District No. 470 Pite No. Village of Primary Regionation District No. 4934 Region City of Charles Control No. 4934 Region City of Charles And Charles No. 4934 Region PULL NAME Fuddrich Marstein	Village of Primery Regimention City of The Primery Regimention City of The Primery Regimentation	District Ho 44934 Baylowed Ho 200
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Similar layouts

Answers the question: How well do classes transfer to similar images?

Early 20th Century Death Records

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Harrison (Construction) Annual (Con	along and the anthropy one can be a set of the set of t	Marcine Par of or reg Marcine Control of the second of the	

Different layouts

Answers the question: How well do classes transfer across different layouts?

1800s-1900s Birth Certificates, Marriage Records, Wills, Census Records, etc.

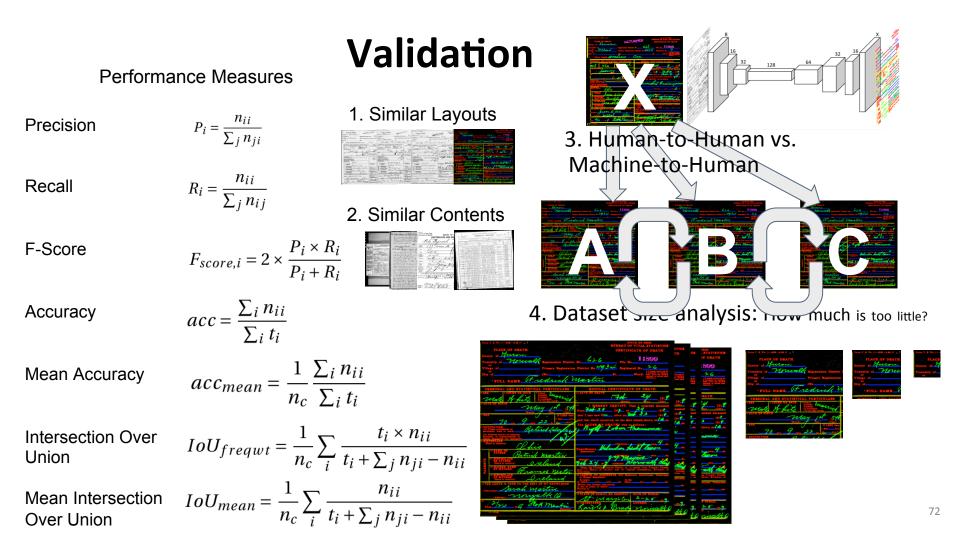
Results on Different form types



Results on Different form types

D	CY.	
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Cuy of	9525 73	
Sex of han 0 Legiti- Child han 0 Legiti- mate? U.e. Twin, Triplet, Triplet,	and { Number Date of (1/77, 19, 190) in case of pirel birth only (North) (Day) (Year)	
RESIDENCE Lei Jo fino OLis	Residence Les plie Otio	
COLOR Male AGE AT LAST 3) OR Male BIRTHDAY (Years) BIRTHPLACE	COLOR OR RACE White AGE AT LAST 23 BIRTHDAY (Years)	
occupation Corfector	occupation Laucemite	
Number of child of this mother	Number of children, of this mother, now living	
CERTIFICATE OF ATTENDING PHYSICIAN OR MIDWIFE* I hereby certify that I attended the birth of this child, and that it occurred on AMAR. 19. 1960, pt		
Given name added from a supplemental report.	Address Life Reg This	
Registrar.	Filed apr. 9919010 John Ellerny Registrar	

Ranfiel marry Cours a Millicenn Tunnin Terry fin	STATE OF CHIO Demos al Vind Besteller CERTIFICATE OF BIRTH
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III	Therpein ohis apr. 7. 10 John Ethons



How to get crisp upsampling?

Train the network at multiple scales, and then at inference time... Inflate the resolution of the image you are predicting on!