

Unriddling and Synthesizing Crosswords using Transformer-based Question-Answer Models

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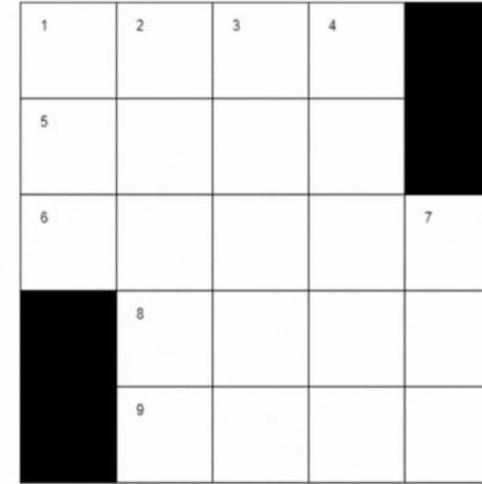
9th October, 2023

Presentation Outline

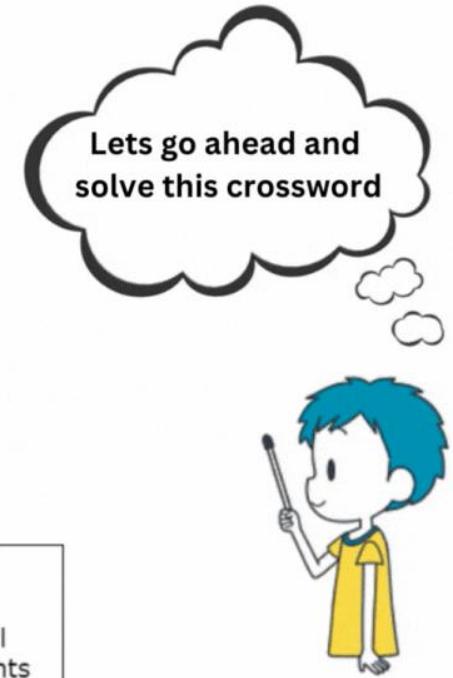
- Motivation
- Project Objectives
- Scope of Project
- Project Application
- Methodology
- Results and Analysis
- Remaining Tasks
- References

Motivation

- Exercise for enhancing cognitive abilities
- Facilitating puzzle solving with AI assistance.
- Advanced technology for automated solutions.
- Engaging puzzle generation for all levels.



ACROSS	DOWN
1. Shivering feeling 5. Solo performance 6. Kitchen furniture 8. Alteration of hair 9. Murder	1. Household animal 2. Verbal assessments 3. Defamation of a person 4. A vibrant flower 7. Common noun suffix



Objectives

- To develop an intelligent computational engine that solves American-style crosswords with varying levels of difficulty
- To design an AI-powered crossword generator for synthesizing American-style crosswords ranging from beginner to expert level

Scope of Project

Project Capabilities:

- Crossword Solver for American-style English crossword problems
- Utilizes OCR system to solve crossword from images
- Crossword Generator generates puzzles with varying difficulty and grid size

Project Limitation:

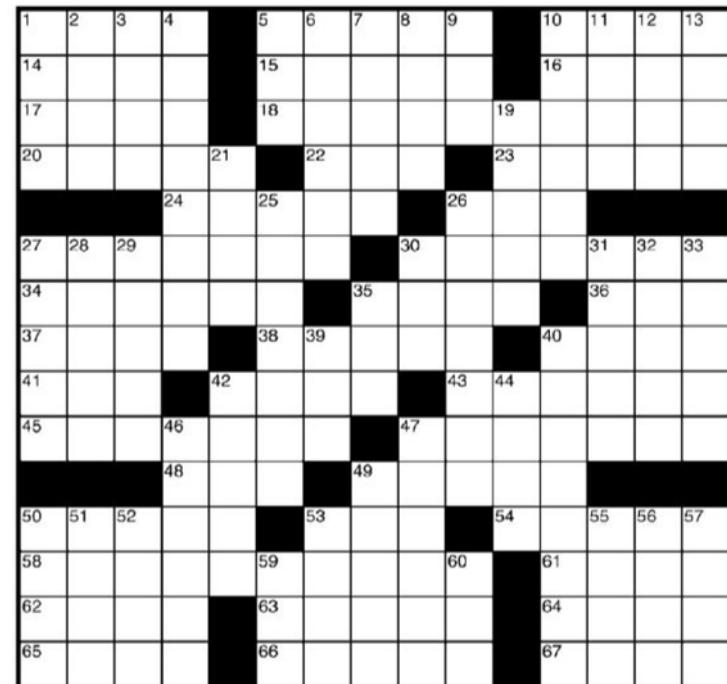
- Limited to English language crossword solving and generation
- Crossword Generator may face challenges in generating puzzles with larger grid sizes

Project Applications

- Crossword Puzzle Aid
 - Helps solve and generate challenging crossword clues.
- Puzzle Analysis and Trend Tracking
 - Analyzes trends in puzzles and clues from puzzle archives
- Educational Puzzle Tool
 - Reinforces learning through interactive crosswords
- Language Learning Tool
 - Expands vocabulary through crossword clue solving
- Interactive Social Media Challenges
 - Engages users with social media crossword challenges

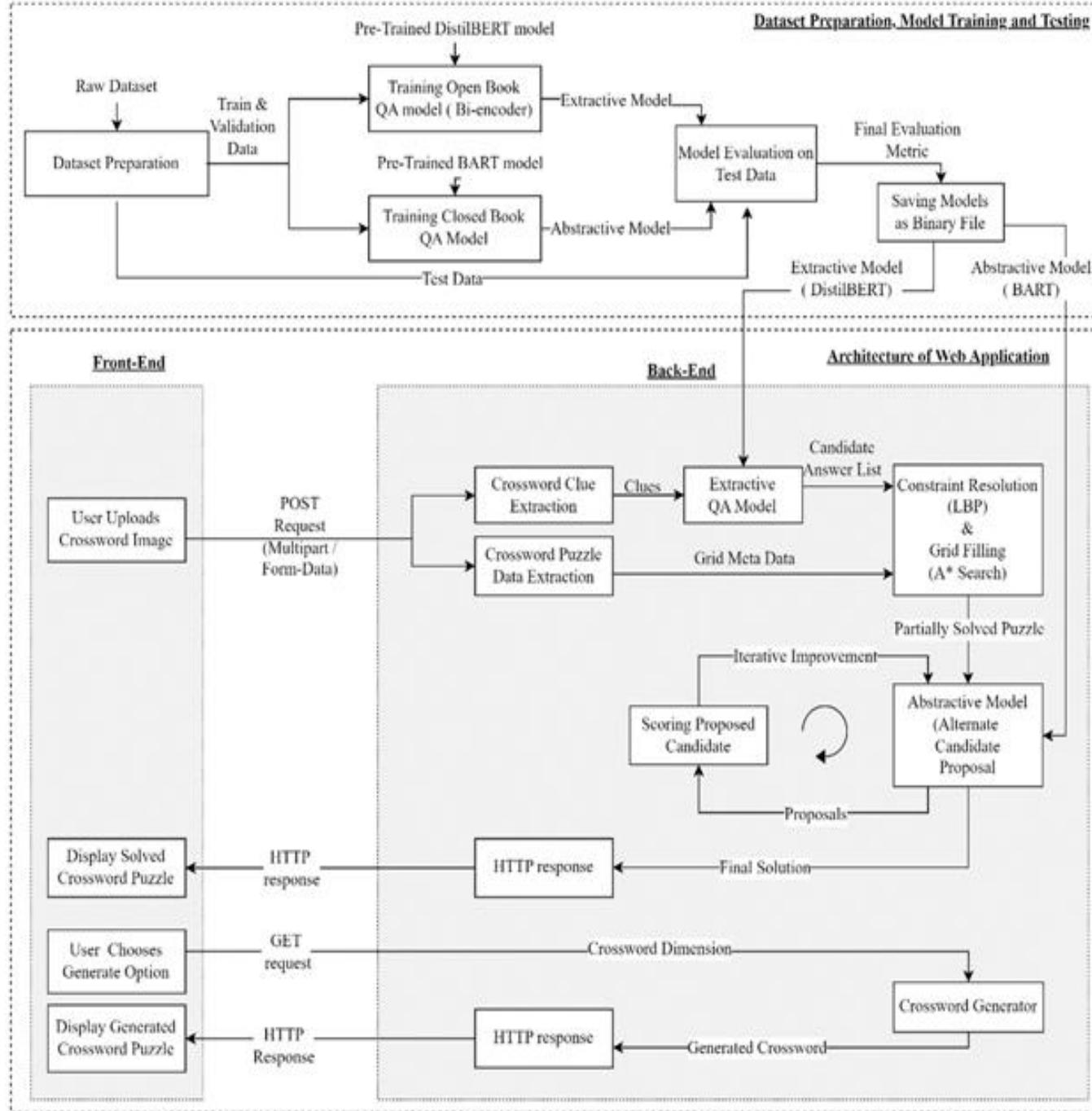
American Styled Crossword

Rule no.	Rule
1	The grid has 90° or 180° rotational symmetry.
2	The grid is a square, typically with dimensions of 15 x 15, 17 x 17 or 21 x 21.
3	The words in the grid should interlock with each other i.e., each square is part of a down and an across clue answer.
4	The numbered squares on the grids represent the start of a word.
5	The number of black squares is generally limited to 1/6 th of the grid on the upper end.
6	American crosswords usually have a theme. Words appearing outside the theme are referred to as fillers. Fillers must not exceed the word length of the themed answers.



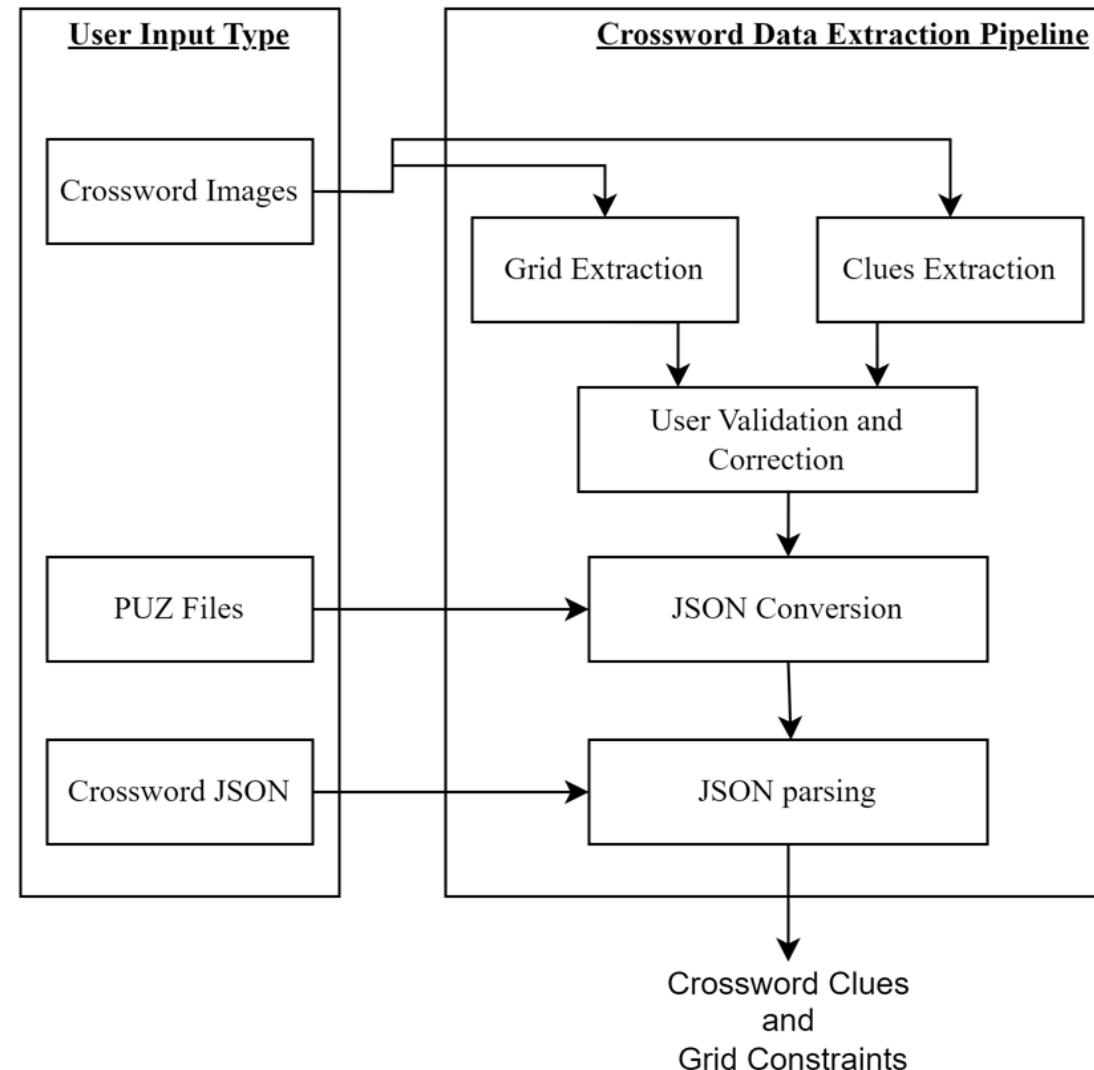
Methodology - [1] (System Block Diagram)

10/9/2023

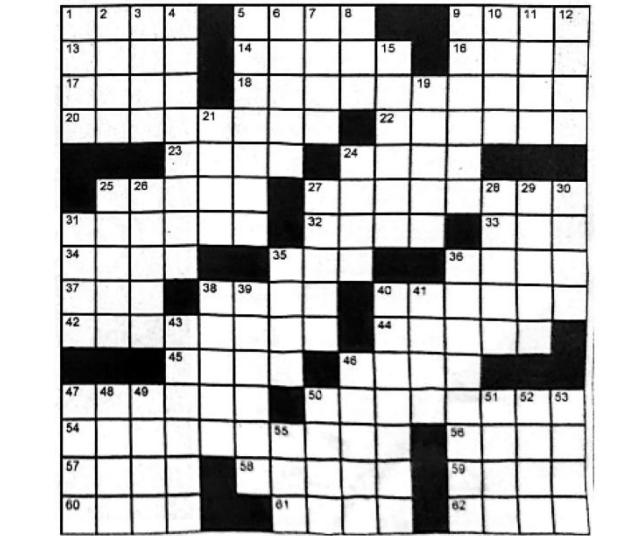


Methodology - [2]

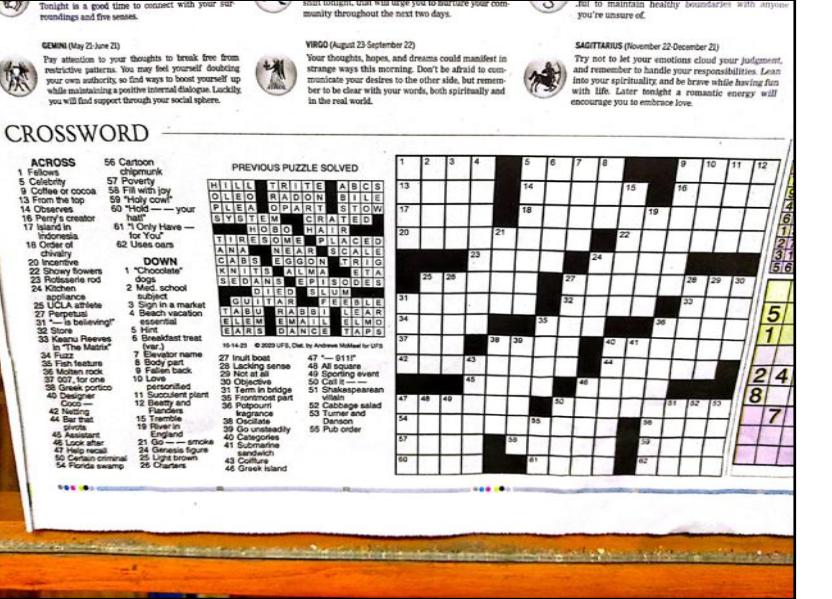
(Crossword Data Input Pipeline)



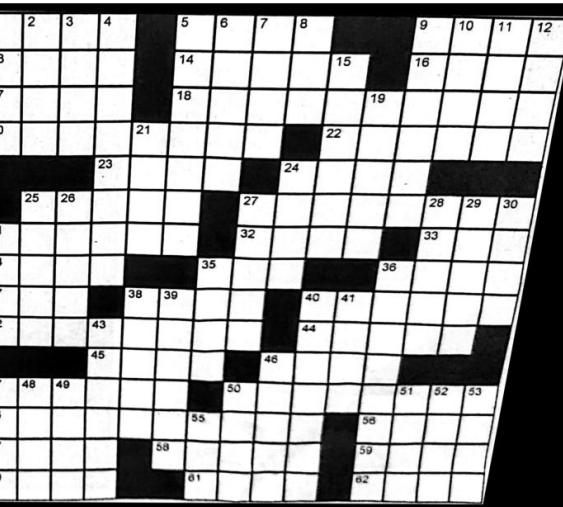
Methodology - [3] (Crossword Data Input Pipeline)



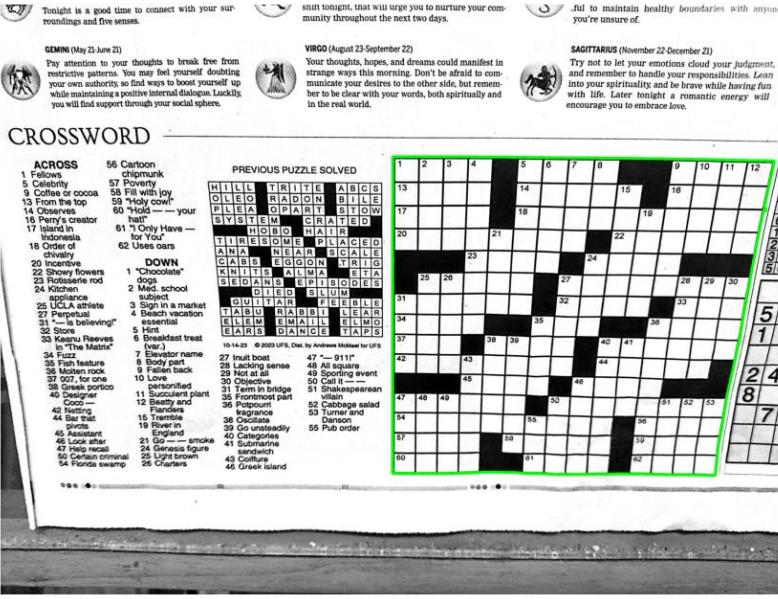
Perspective Transformed Image



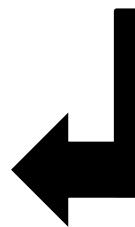
Original Image



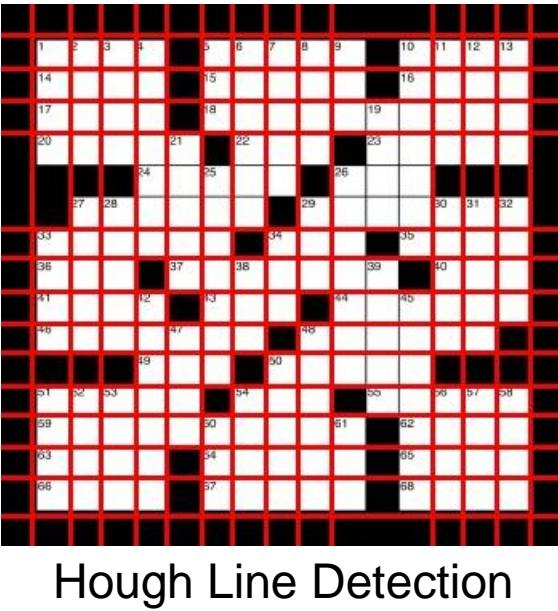
Extracted Grid Image



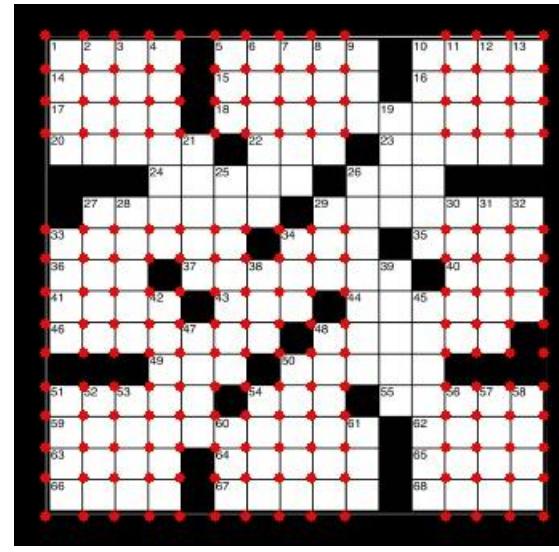
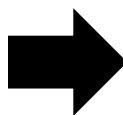
Largest Contour Detection



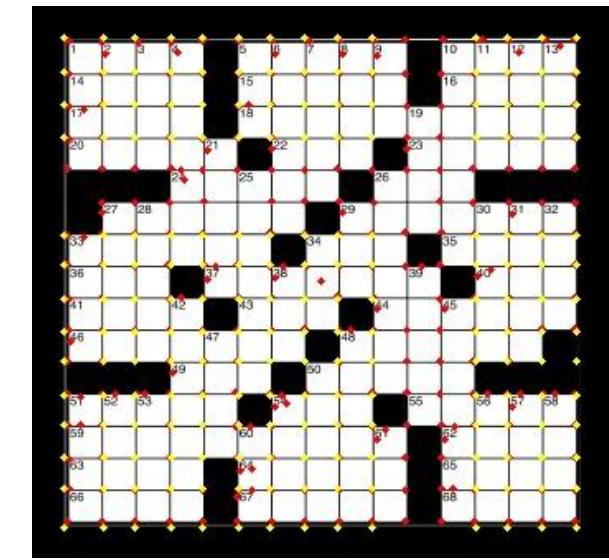
Methodology - [4] (Crossword Data Input Pipeline)



Hough Line Detection

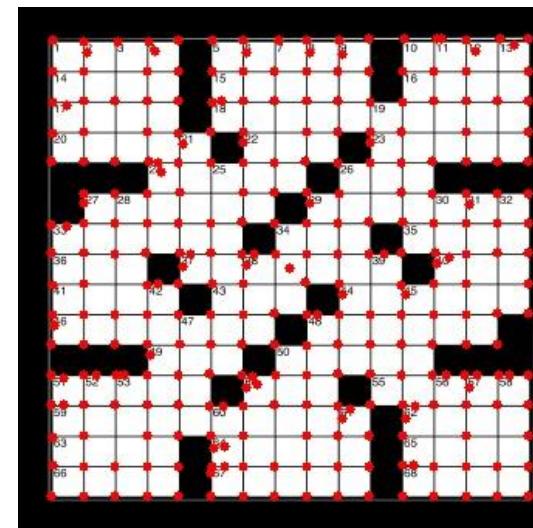
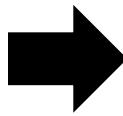


Intersection Points



Combined Corners

CLAHE Image

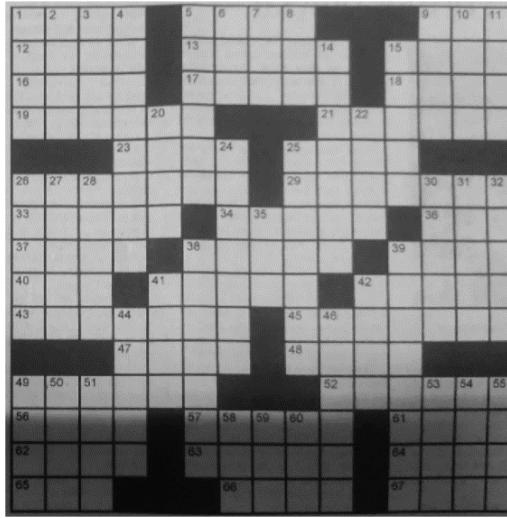


Harris Corner Detection

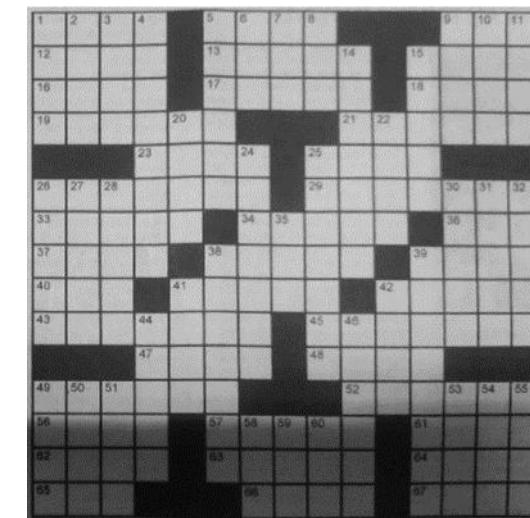


Methodology - [5] (Crossword Data Input Pipeline)

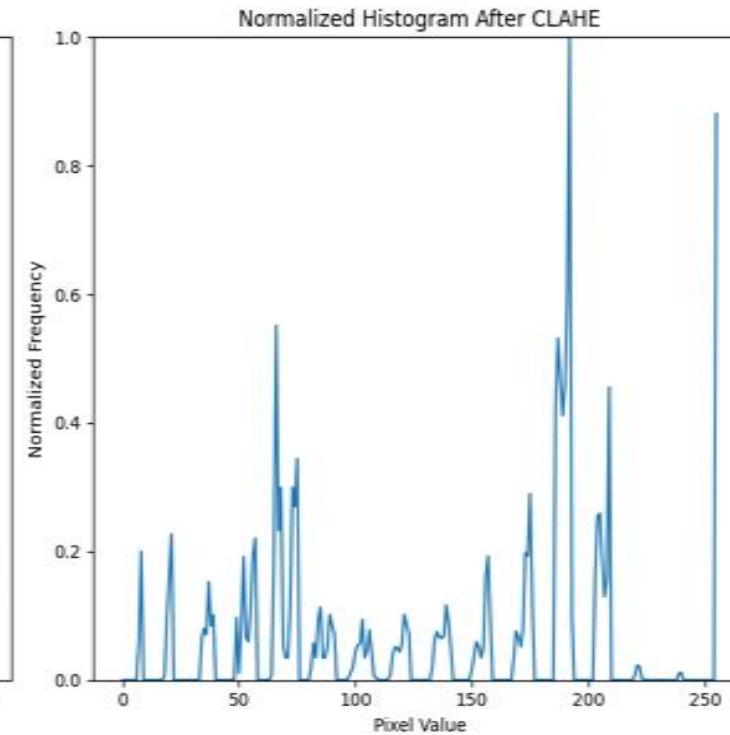
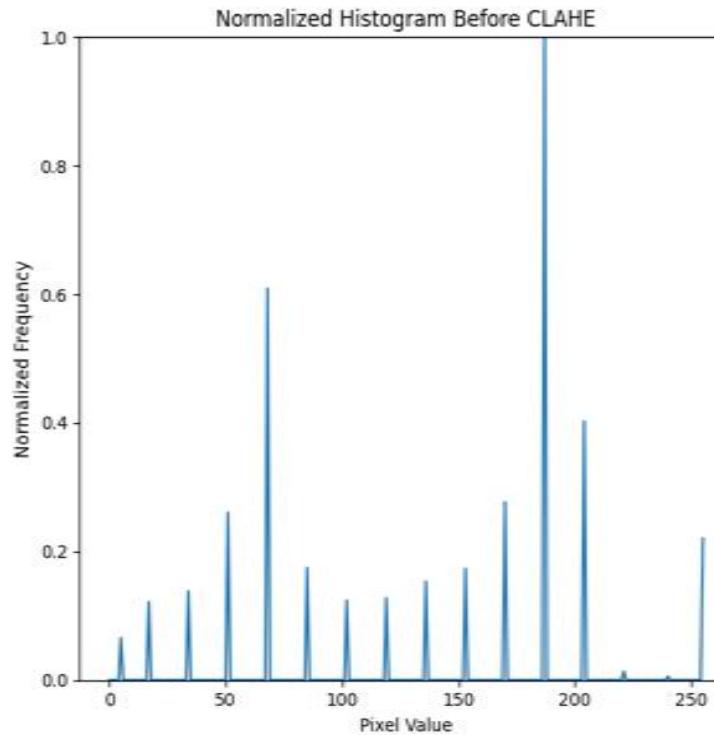
10/9/2023



Before CLAHE

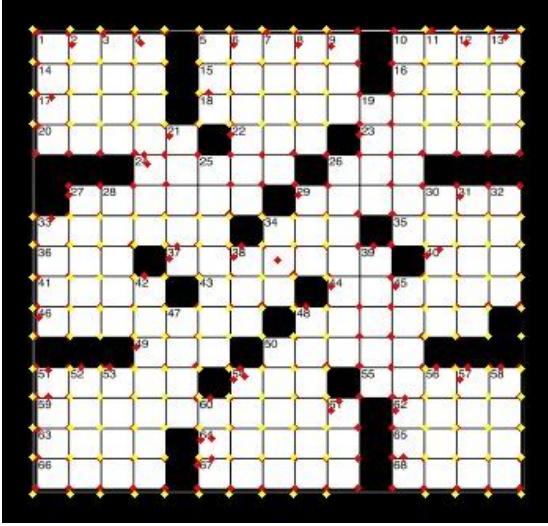


After CLAHE

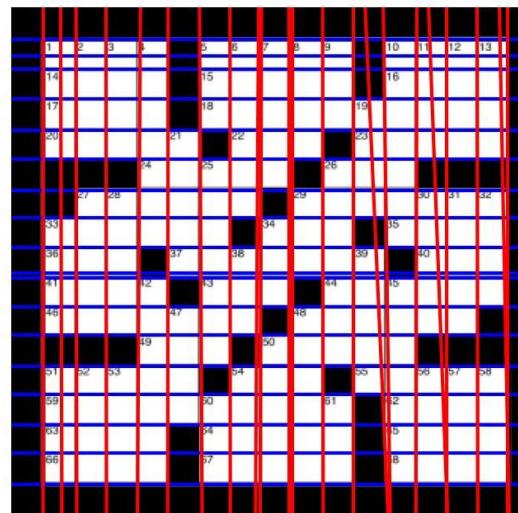
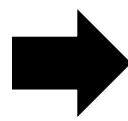


11

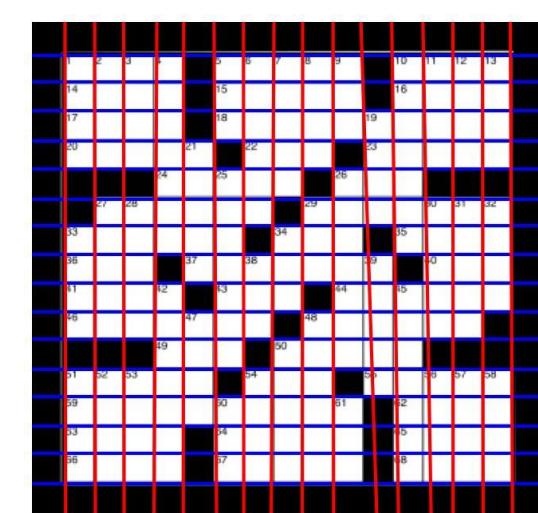
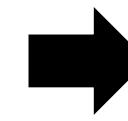
Methodology - [6] (Crossword Data Input Pipeline)



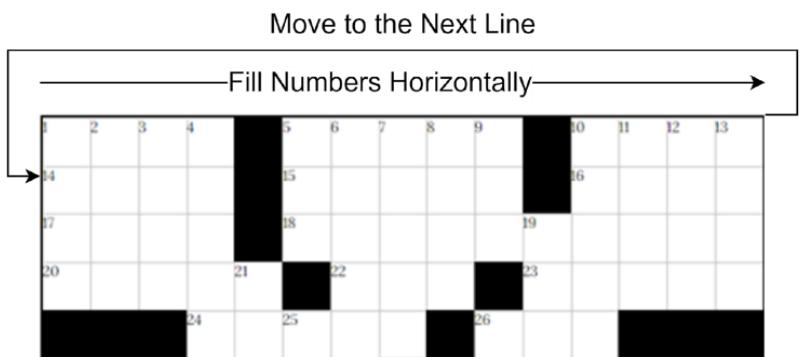
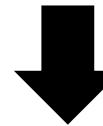
Combined Corners



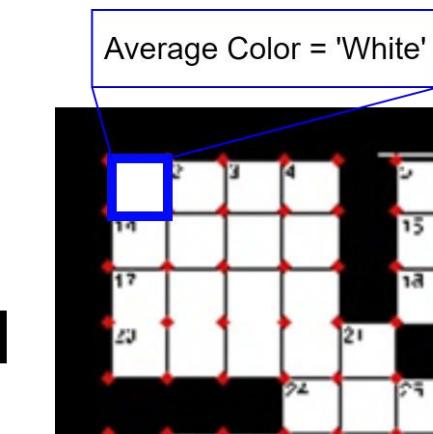
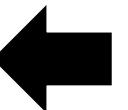
Fitting Regression Lines



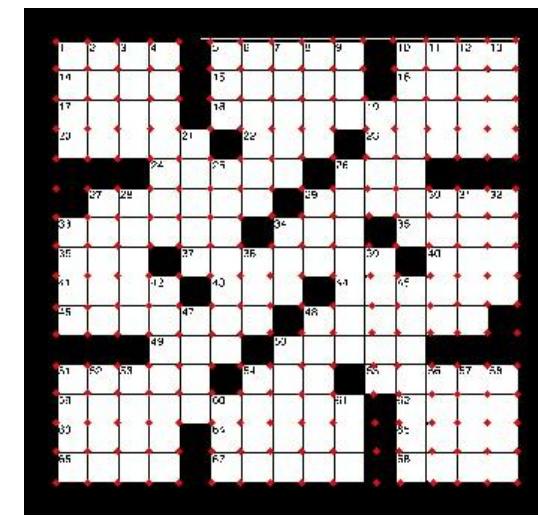
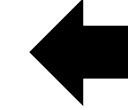
Filtered Regression Lines



Cell number computation
using grid color information

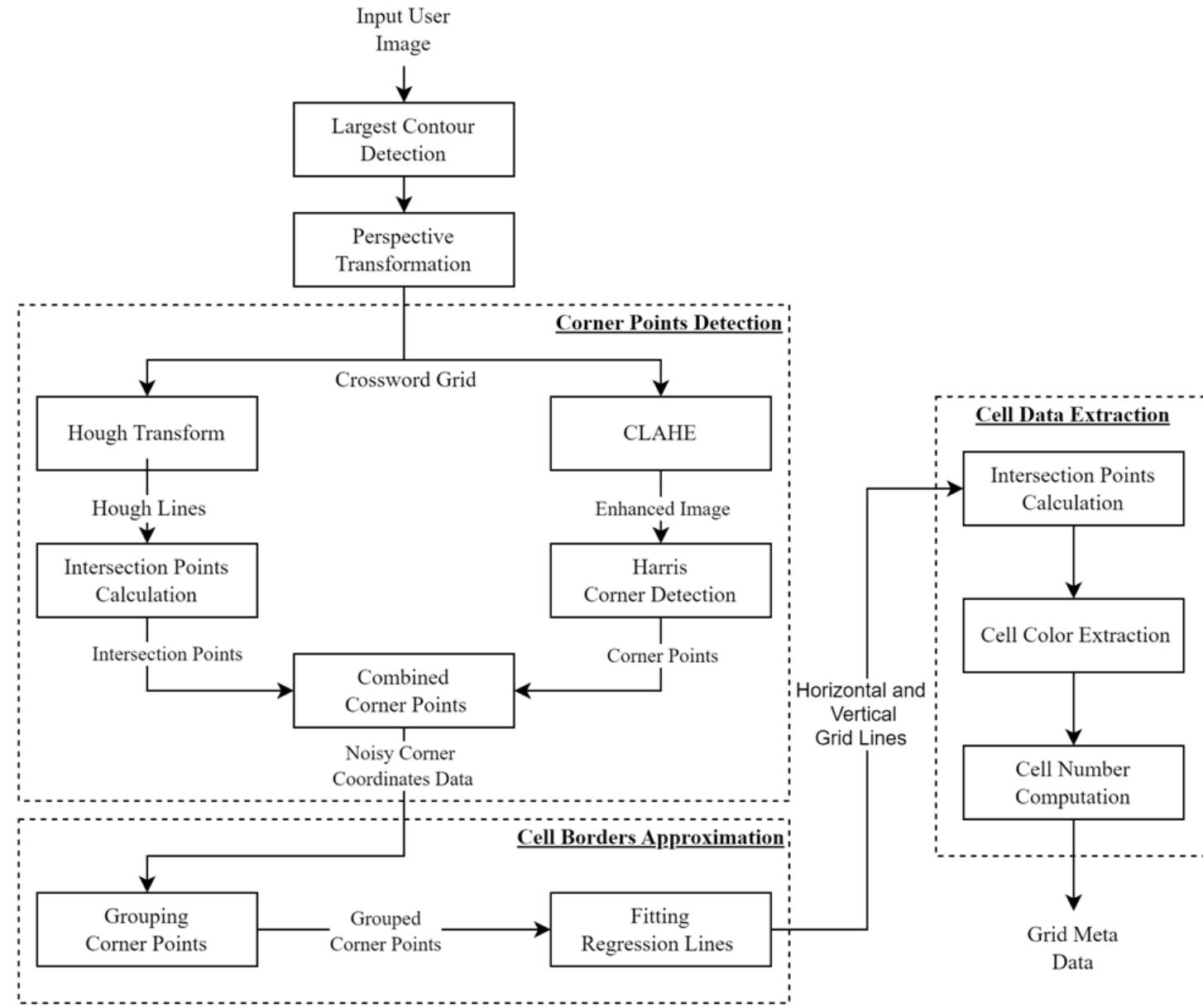


Cell color extraction by
computing average pixel
value

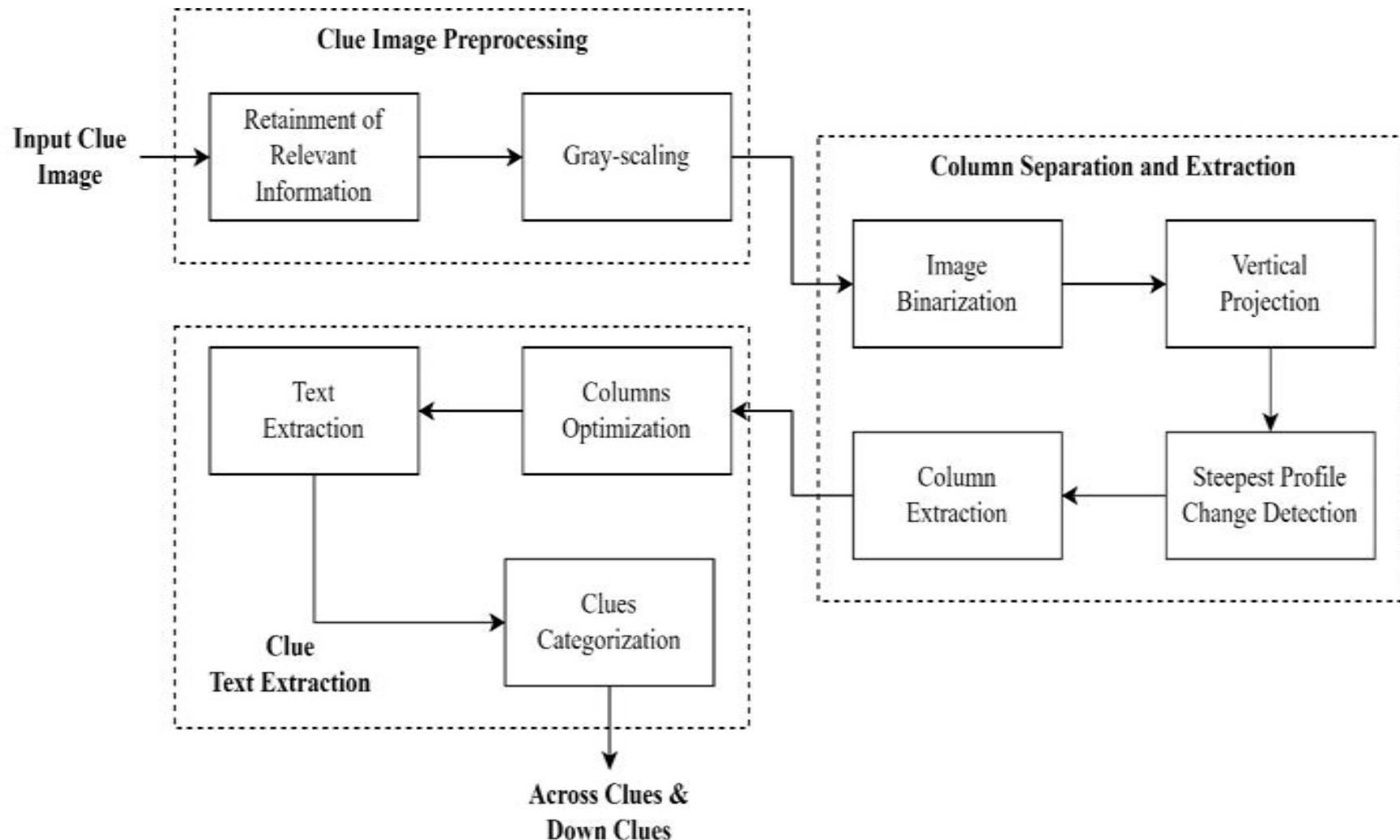


Approximated Cell Borders

Methodology - [7] (Crossword Data Input Pipeline)



Methodology - [8] (Clue Extraction)

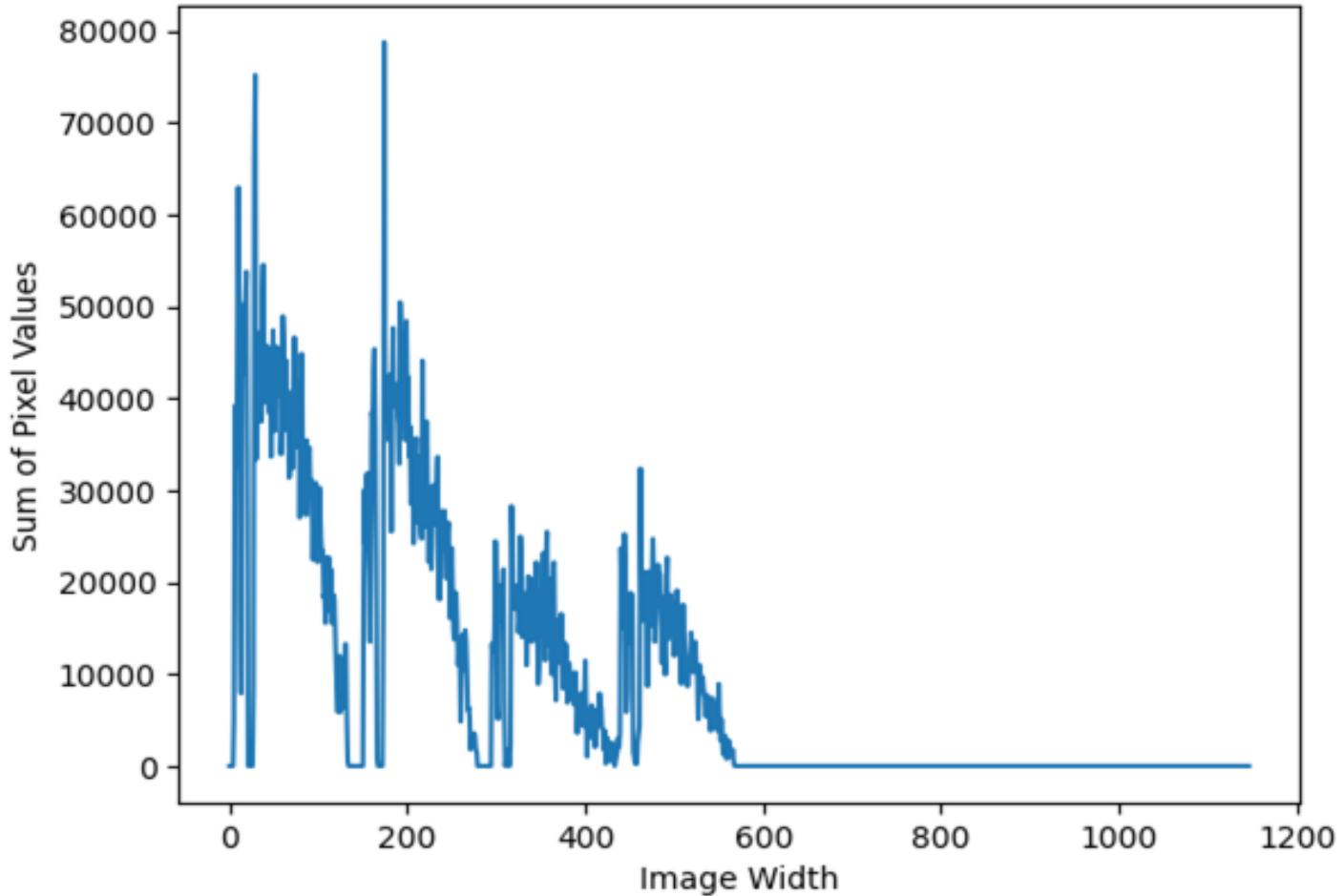


Methodology - [9]

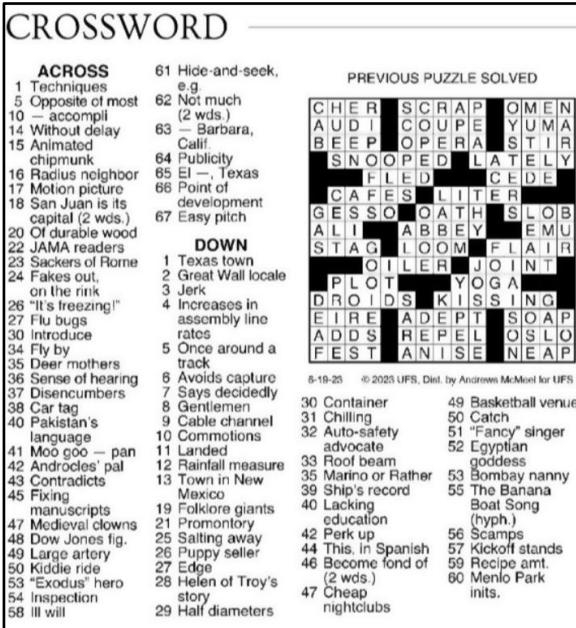
(Clue Extraction)

Vertical Projection Profile

- Provides a histogram-like representation of how the white pixels are distributed vertically in the image.
- Text and non-text regions are characterized by peaks and valleys, respectively
- Calculates the sum of pixel values along the vertical column of image.



Methodology - [10] (Clue Extraction)



Clues Image

ACROSS

- Techniques e.g.
- Opposite of most
- accompli (2 wds.)
- Without delay
- Animated chipmunk
- Radius neighbor
- Motion picture
- San Juan is its capital (2 wds.)
- Of durable wood
- JAMA readers
- Sackers of Rome
- Fakes out, on the rink
- "It's freezing!"
- Flu bugs
- Introduce
- Fly by
- Deer mothers
- Sense of hearing
- Disencumbers
- Car tag
- Pakistan's language
- Moo goo — pan
- Androcles' pal
- Contradicts
- Fixing manuscripts
- Medieval clowns
- Dow Jones fig.
- Large artery
- Kiddie ride
- "Exodus" hero
- Inspection
- Ill will
- Hide-and-seek, e.g.
- Not much (2 wds.)
- Barbara, Calif.
- Publicity
- Radius neighbor
- El —, Texas
- Point of development
- Easy pitch
- Texas town
- Great Wall locale
- Jerk
- Increases in assembly line rates
- Once around a track
- Avoids capture
- Says decidedly
- Container
- Chilling
- Gentlemen
- Auto-safety advocate
- Pakistan's language
- Moo goo — pan
- Androcles' pal
- Contradicts
- Fixing manuscripts
- Medieval clowns
- Dow Jones fig.
- Large artery
- Kiddie ride
- "Exodus" hero
- Inspection
- Ill will
- Basketball venue
- Catch
- "Fancy" singer
- Egyptian goddess
- Bombay nanny
- The Banana Boat Song (hyp.)
- Landing
- Rainfall measure
- In New Mexico
- Ship's record
- Boat Song (hyp.)
- Promontory
- Salting away
- Puppy seller
- Become fond of (2 wds.)
- Recipe amt.
- Menlo Park inits.
- Scamps
- Roof beam
- Marino or Rather
- The Banana Boat Song (hyp.)
- Education
- Perk up
- This, in Spanish
- Edge
- Helen of Troy's story
- Cheap nightclubs
- Half diameters

DOWN

- Texas town
- Great Wall locale
- Jerk
- Increases in assembly line rates
- Once around a track
- Avoids capture
- Says decidedly
- Gentlemen
- Cable channel
- Commotions
- Landed
- Rainfall measure
- In New Mexico
- Ship's record
- Boat Song (hyp.)
- Promontory
- Salting away
- Puppy seller
- Become fond of (2 wds.)
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- Egyptian goddess
- Bombay nanny
- The Banana Boat Song (hyp.)
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- Edge
- Helen of Troy's story
- Cheap nightclubs
- Half diameters

Processed Image

ACROSS

- Techniques e.g.
- Opposite of most
- accompli (2 wds.)
- Without delay
- Animated chipmunk
- Radius neighbor
- Motion picture
- San Juan is its capital (2 wds.)
- Of durable wood
- JAMA readers
- Sackers of Rome
- Fakes out, on the rink
- "It's freezing!"
- Flu bugs
- Introduce
- Fly by
- Deer mothers
- Sense of hearing
- Disencumbers
- Car tag
- Pakistan's language
- Moo goo — pan
- Androcles' pal
- Contradicts
- Fixing manuscripts
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- Dow Jones fig.
- Large artery
- Kiddie ride
- "Exodus" hero
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DOWN

- Texas town
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- Auto-safety advocate
- Egyptian goddess
- Bombay nanny
- The Banana Boat Song (hyp.)
- Education
- Perk up
- This, in Spanish
- Edge
- Helen of Troy's story
- Cheap nightclubs
- Half diameters

Columns Detected and Separated

Methodology - [11] (Clue Extraction)



Input Image

Clue Extraction
and Categorization

Across

1. Techniques
5. opposite of most
10. _ accomplil
14. Without delay
-
-

64. Publicity
65. El __, Texas
67. Easy pitch

Down

1. Texas town
2. Great Wall locate
4. Jerk
5. Increase in assembly line rates
-
-
57. Kickoff stands
59. Recipe amt.
60. Menio Park inits

Extracted Clues

Methodology - [12] (Crossword Data Input Pipeline)

JSON Files

```
{  
  "size": { "rows": 15, "cols": 15 },  
  "grid": [  
    " ", " ", " ", " ", " ", " ", " ", " ", " ", " ", " ", " ",  
    ".", " .", " ", " ", " ", .....  
  ],  
  "gridnums": [  
    1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 0, 0,  
    11, 12, 13, 14, 0, 0, 0, 0, 0, 0, 0, 0, 0, .....  
  ],  
  "clues": {  
    "across": [  
      "1. Shoot!",  
      "11. It's turned down at a Hotel", .....  
    ],  
    "down": [  
      "1. Kids' game cry",  
      "2. Unit of measure that has a  
        shared etymology with "inch", .....  
    ]  
  }  
}
```

PUZ Files

- PUZ file is a binary file
- Has designated sections containing:
 - File Headers
 - Grid State (Marking Empty or filled squares)
 - Across and Down Clues
- Requires parsing binary file and conversion to JSON

Methodology – [13]

(Dataset Compilation & Extension)

- Utilize publicly available Berkeley Crossword solver datasets: 6M+ clue-answer pairs from 26 media outlets up to late 2020

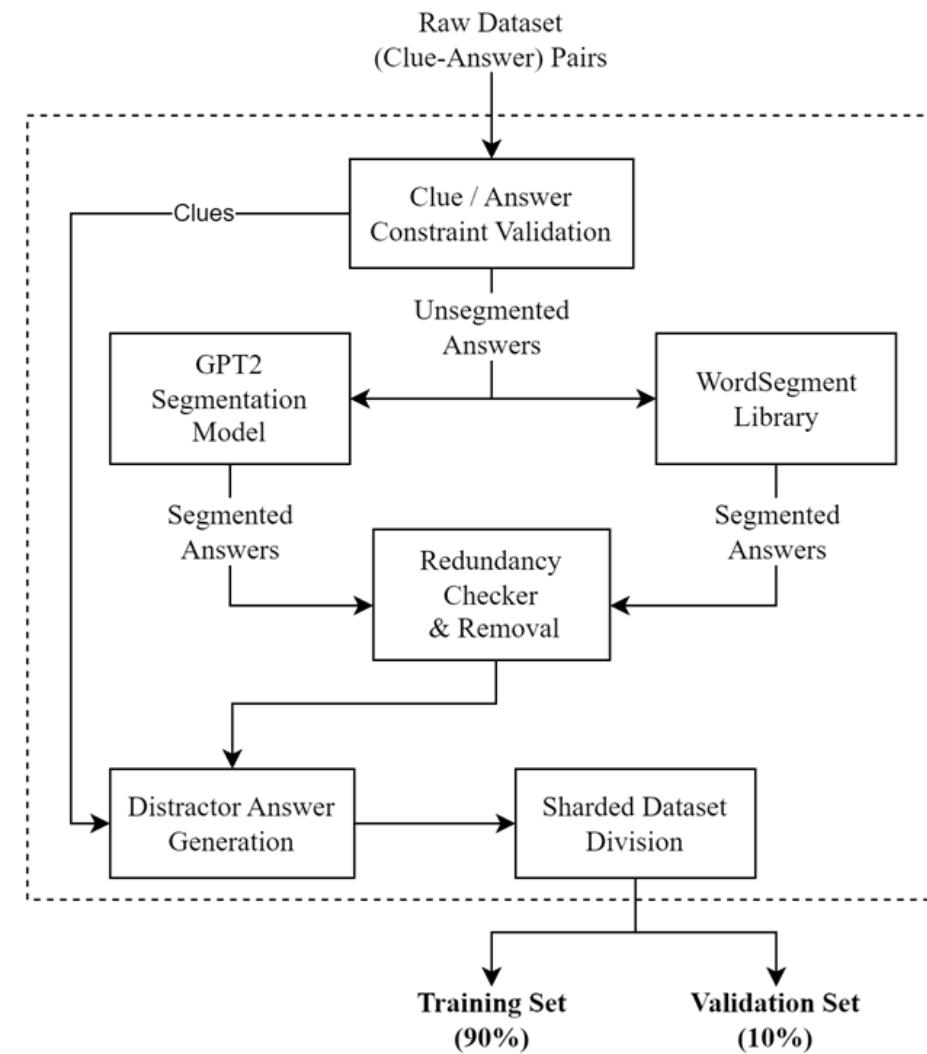
	Train	Validation	Test
QA Pairs	6.42 M	30.4 K	21.3 K
Answer Set	437.8 K	17.2 K	13.4 K
Timeframe	1951-2019	2020	2021

- Enriched dataset with 4M Chinese clue-answer pairs, resulting in approximately 400K unique pairs due to BCS source overlap.
- Scrapped from 21 diverse sources, with some overlap with BCS, primarily focused on post-2021 pairs.
- Test Puzzle Source: NYT's (Jul-Sept, 2023) & 'The Kathmandu Post's (Sept-Oct, 2023).

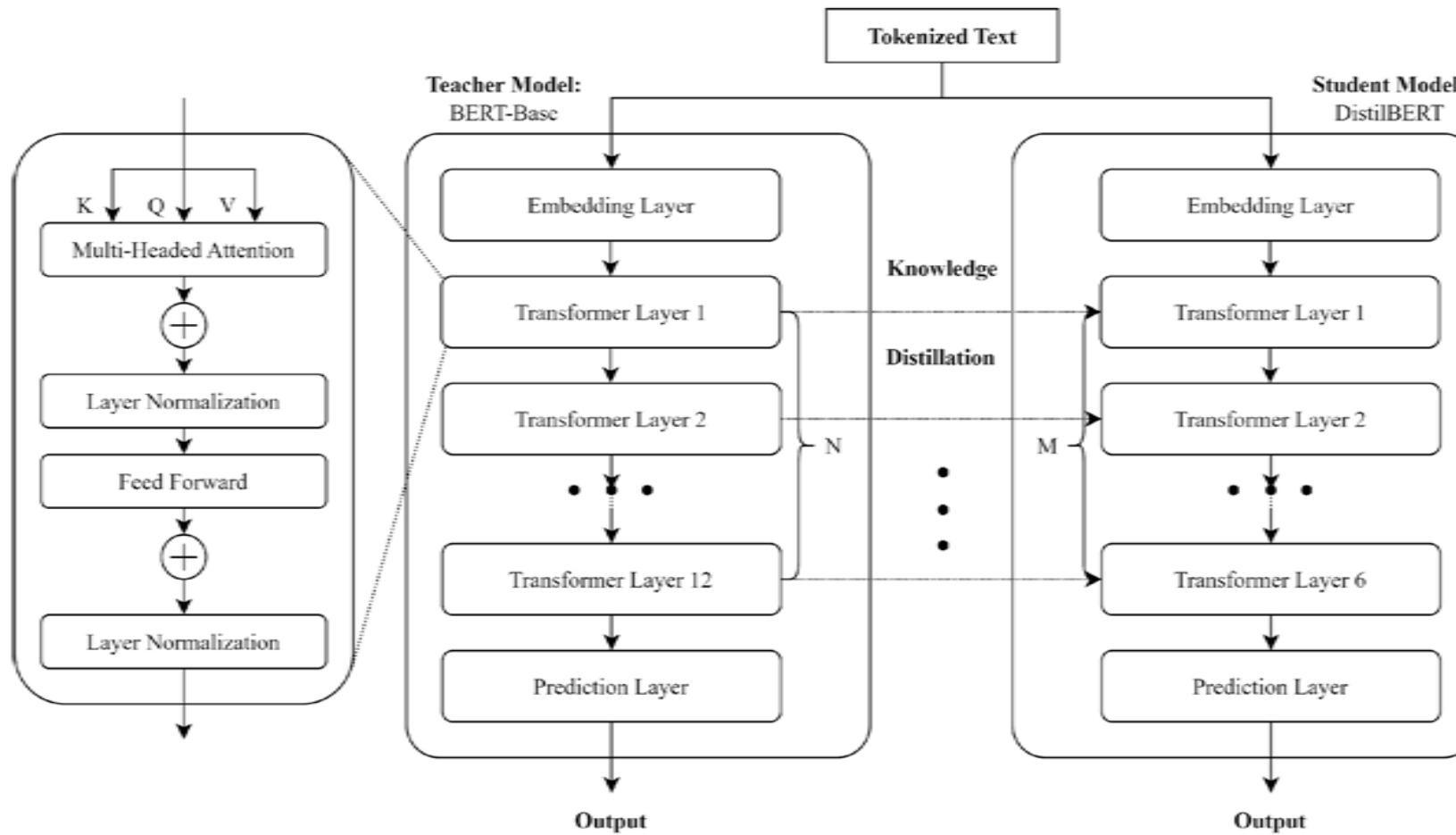
Methodology – [14] (Dataset Preprocessing)

Making Data ML Ready

- Validating Clue / Answer Constraints
- Using pre-trained GPT2 & WordSegment library for word segmentation on crossword answers
- Remove redundant clue-answer pairs from dataset
- Distractor answer generation using TF-IDF
- Train-Validation Set Split (90% - 10%)



Methodology – [15] (Architecture of DistilBERT Model)

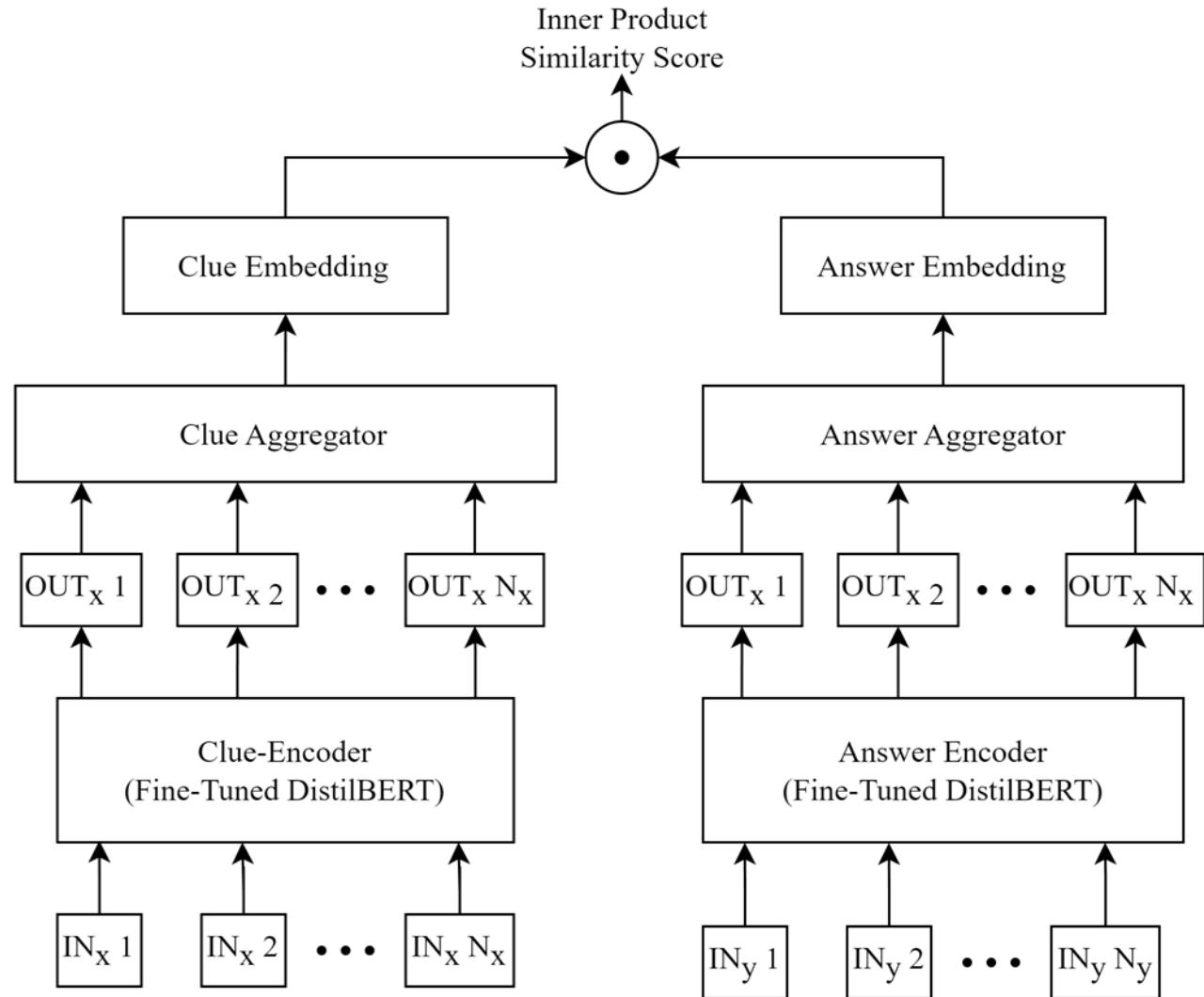


DistilBERT Model Features

- Distilled Knowledge by condensing BERT from 12 to 6 Encoder layers.
- DistilBERT-base Parameter Count: 67 M
- Achieved 3% performance drop compared to BERT.
- Significantly faster training and inferencing.
- Reduced memory footprint and practical for resource-constrained environment.

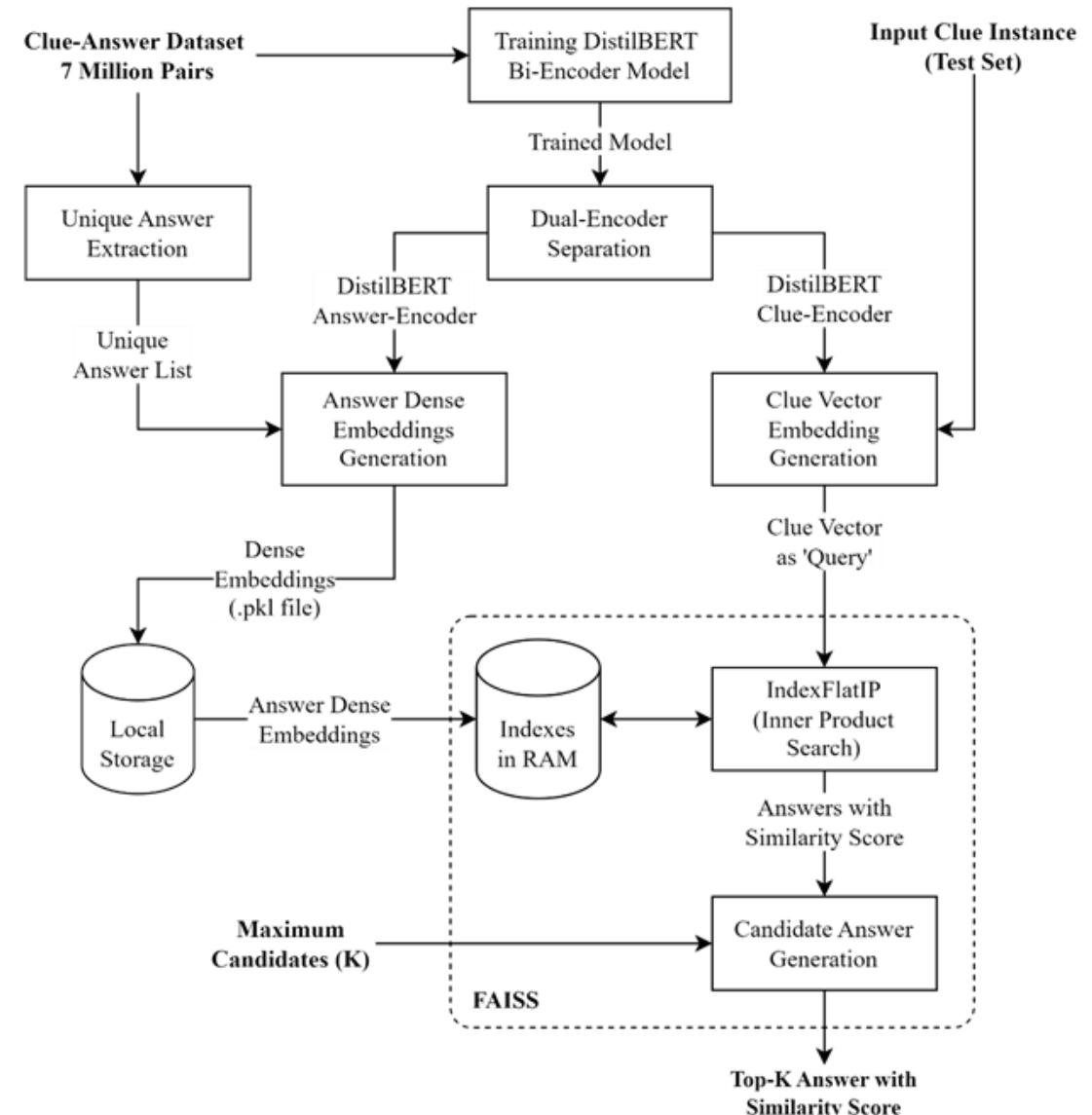
Methodology – [16] (Bi-Encoder Architecture)

- **Goal:** Map clues and answers embeddings into a shared feature-vector space
- **Strength:** Faster prediction by caching the encoded candidate answers
- **Encoder:** Utilizes two DistilBERT encoders separately for clue and answer
- **Similarity Measure:** Inner Product
- **Loss Function:** Negative Log-Likelihood (NLL) loss for training



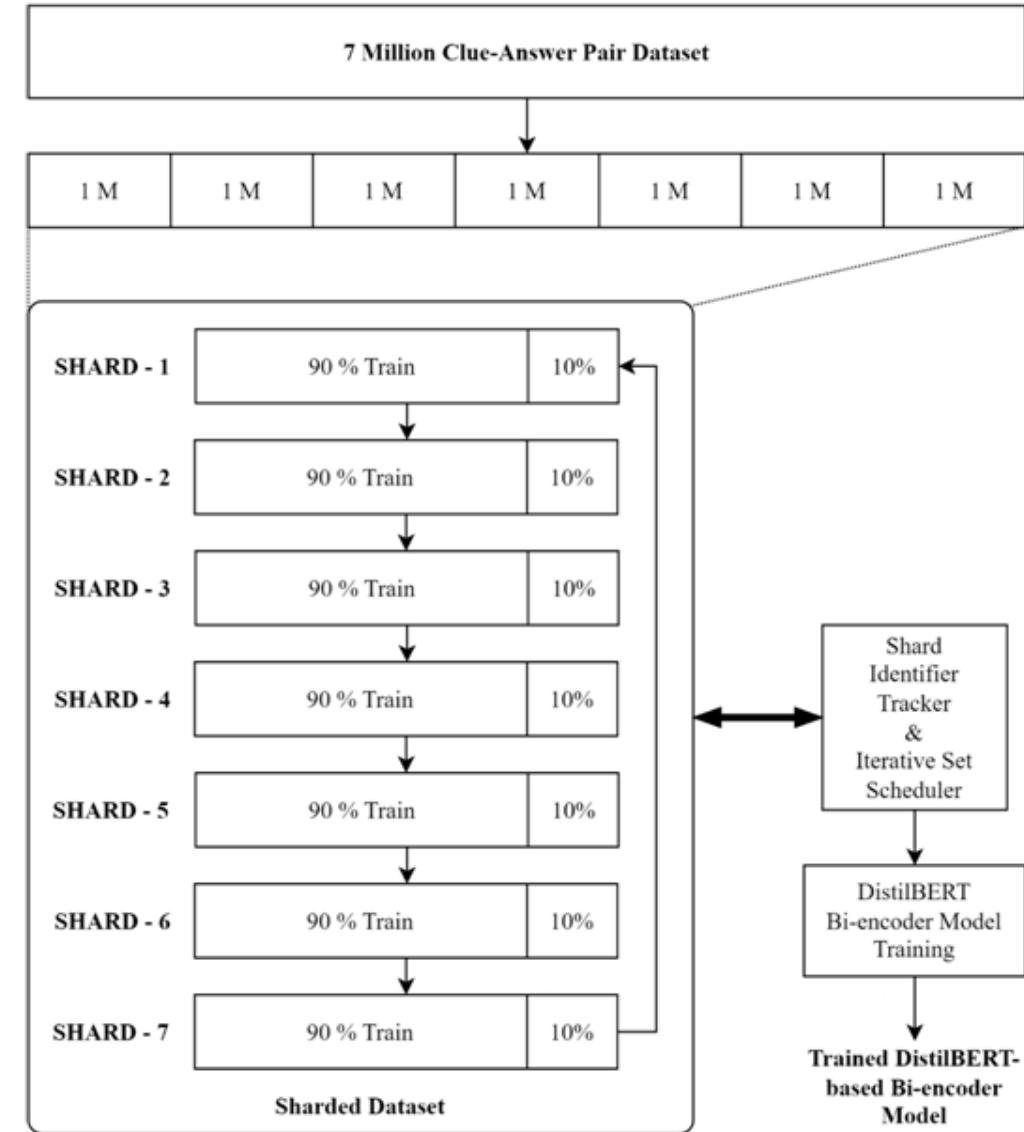
Methodology – [17] (Dense Answer Retrieval System)

- **DAR:** Efficiently indexes answers in a lower-dimensional space for top-K retrieval.
- **Vector Embeddings:** Encodes unique answers using DistilBERT, resulting in dense vector representations stored as .pkl files.
- **Clue Encoding:** Encodes test clues with DistilBERT Clue-Encoder to create vector representations.
- **Similarity Assessment:** Employs FAISS with Inner Product (FlatIP) for similarity search to identify Top-K answers.
- **Parameter Control:** 'Maximum Candidates' parameter determines the Top-K answers, assisting constraint resolution.



Methodology – [18] (DistilBERT Bi-Encoder Training Setup)

- Due to resource constraints, we split seven million clue-answer pairs into seven random one-million-pair shards.
- Each shard allocated 90% for training and 10% for validation.
- Used an iterative scheduler, training each shard for one epoch before moving to the next.
- This approach yielded seven epochs for the entire DistilBERT Bi-encoder dataset, equivalent to 49 epochs when considering individual shard training.



Methodology – [19] (Instrumentation)

Hardware Resources

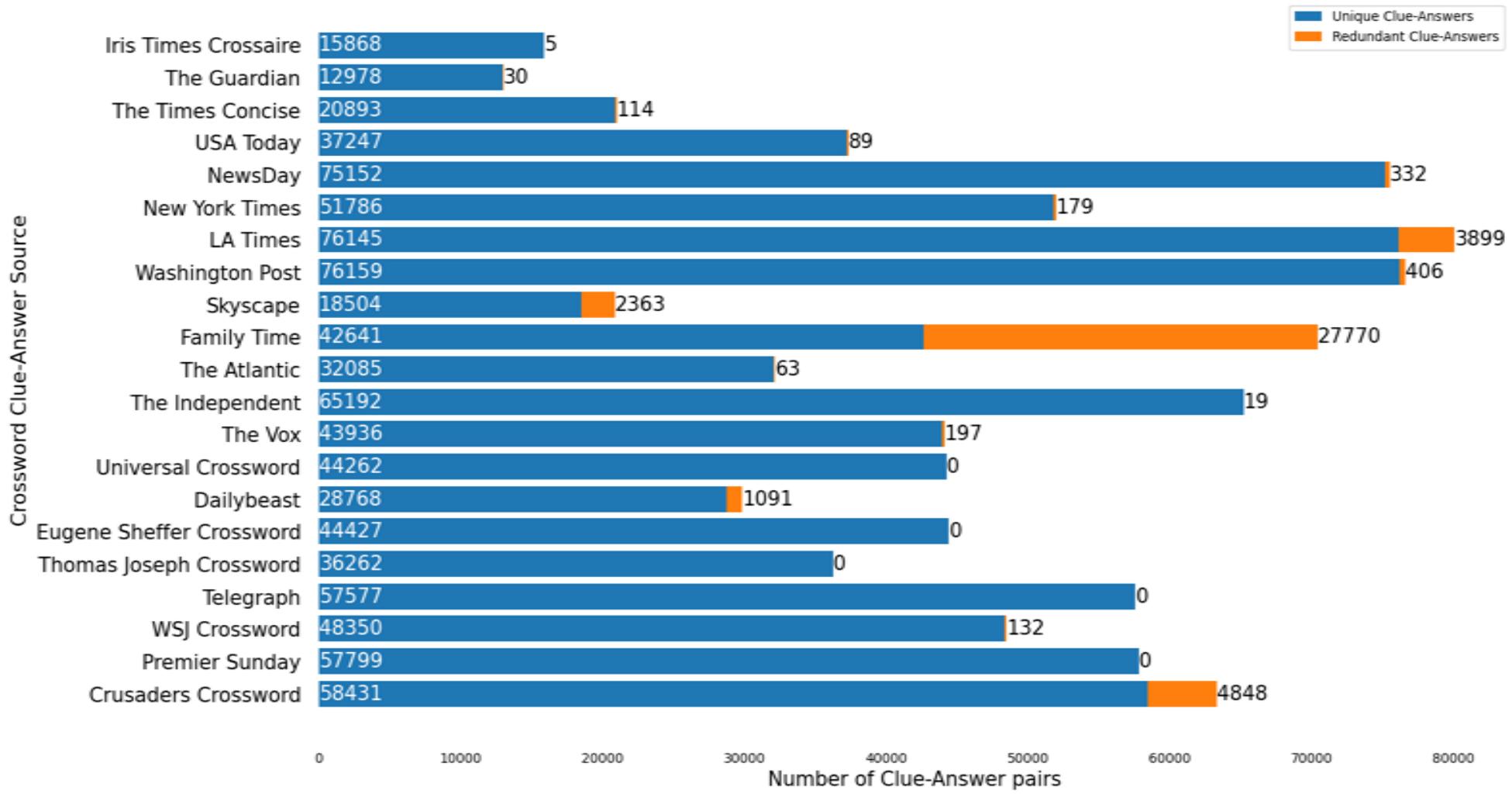
Parameter	Google Colab	Kaggle Kernel
GPU Name	NVIDIA K80 / T4	NVIDIA Tesla P100
GPU Architecture	NVIDIA Turing	NVIDIA Pascal
GPU Memory	12GB	16GB (16.28GB Usable) CoWoS HBM2 at 732 GB/s
NVIDIA CUDA Cores	4992	3584
RAM	~ 12 GB Available	~ 15.26 GB Available
Disk Storage	~ 108GB Available	~ 155 GB Available
CPU	2x Intel Xeon @ 2.30 GHz	1 x single core hyper threaded i.e. (1 core, 2 threads) Xeon Processor @2.2Ghz, 56MB Cache

Software Resources

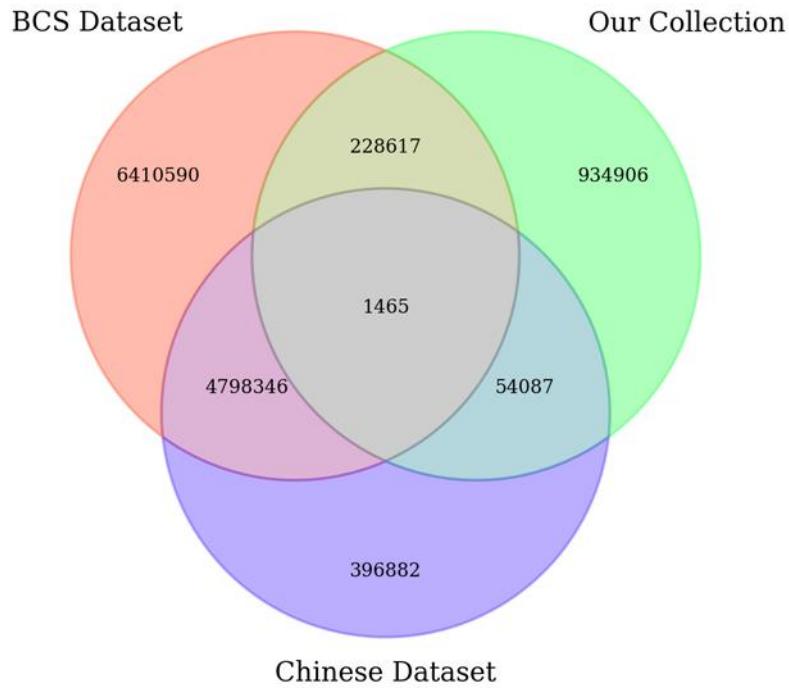
Tesseract
Django Framework
Pytorch
OpenCV

Results and Analysis – [1]

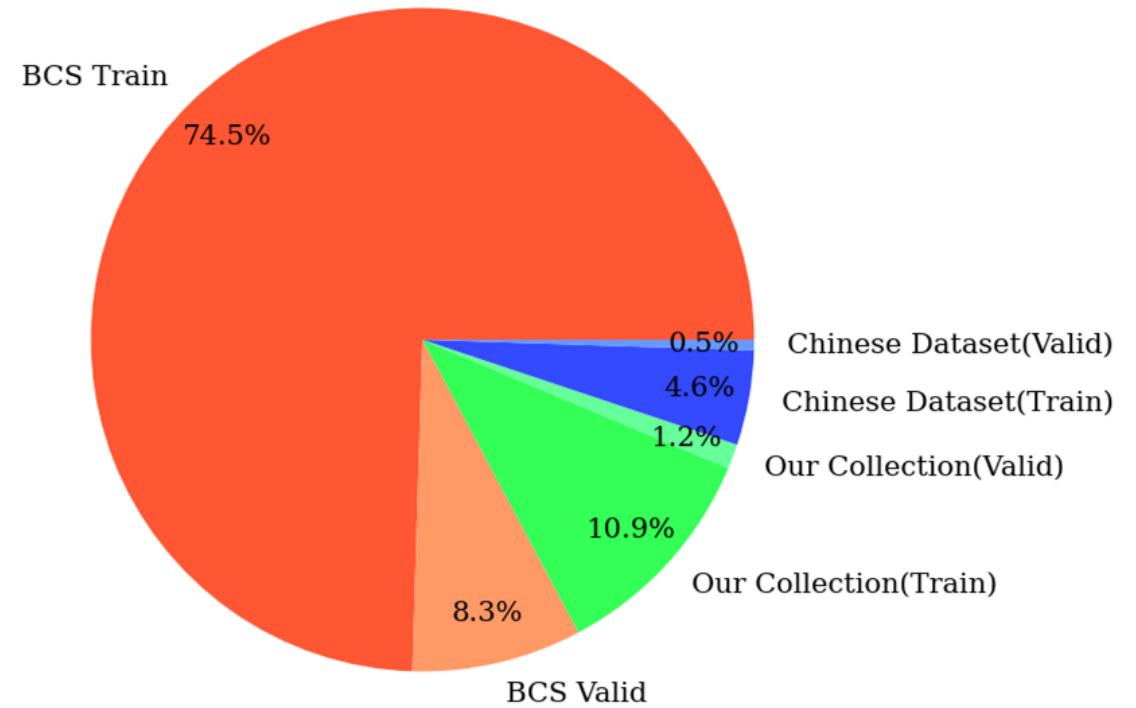
(Data Collection from 21 Online Sources)



Results and Analysis – [2] (Overall Dataset Visualization)



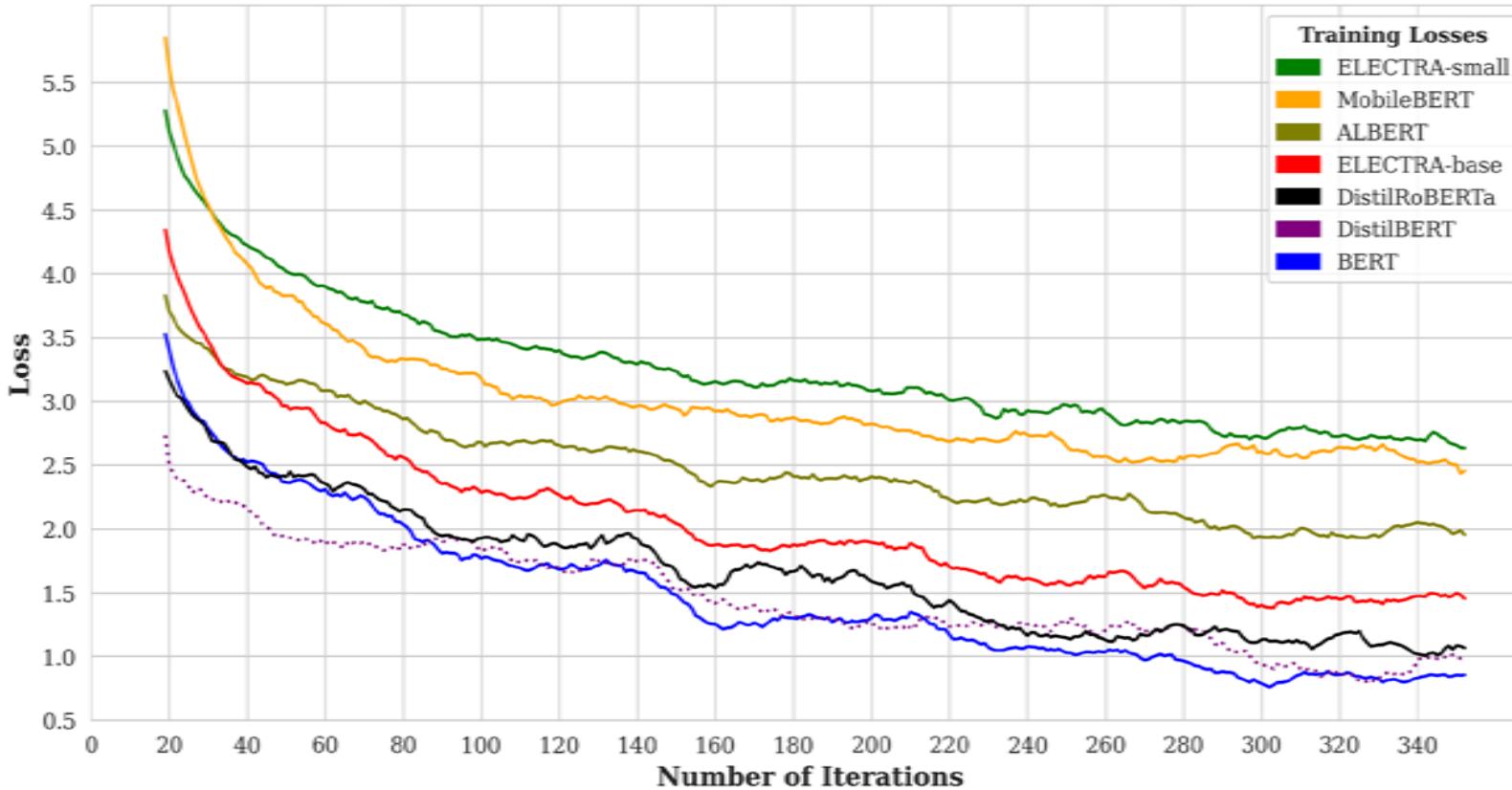
Data Overlap Among Various Sources



Overall Dataset Composition

Results and Analysis – [3]

(Training Loss comparison between various Models)



- Balancing size and performance is key for bi-encoder due to dual encoders and storage limits.
- Tested seven transformers on a partial dataset to gauge performance.
- BERT excels; smaller models like ALBERT and MobileBERT underperform. DistilBERT shines, closely matching BERT's performance.

Results and Analysis – [4]

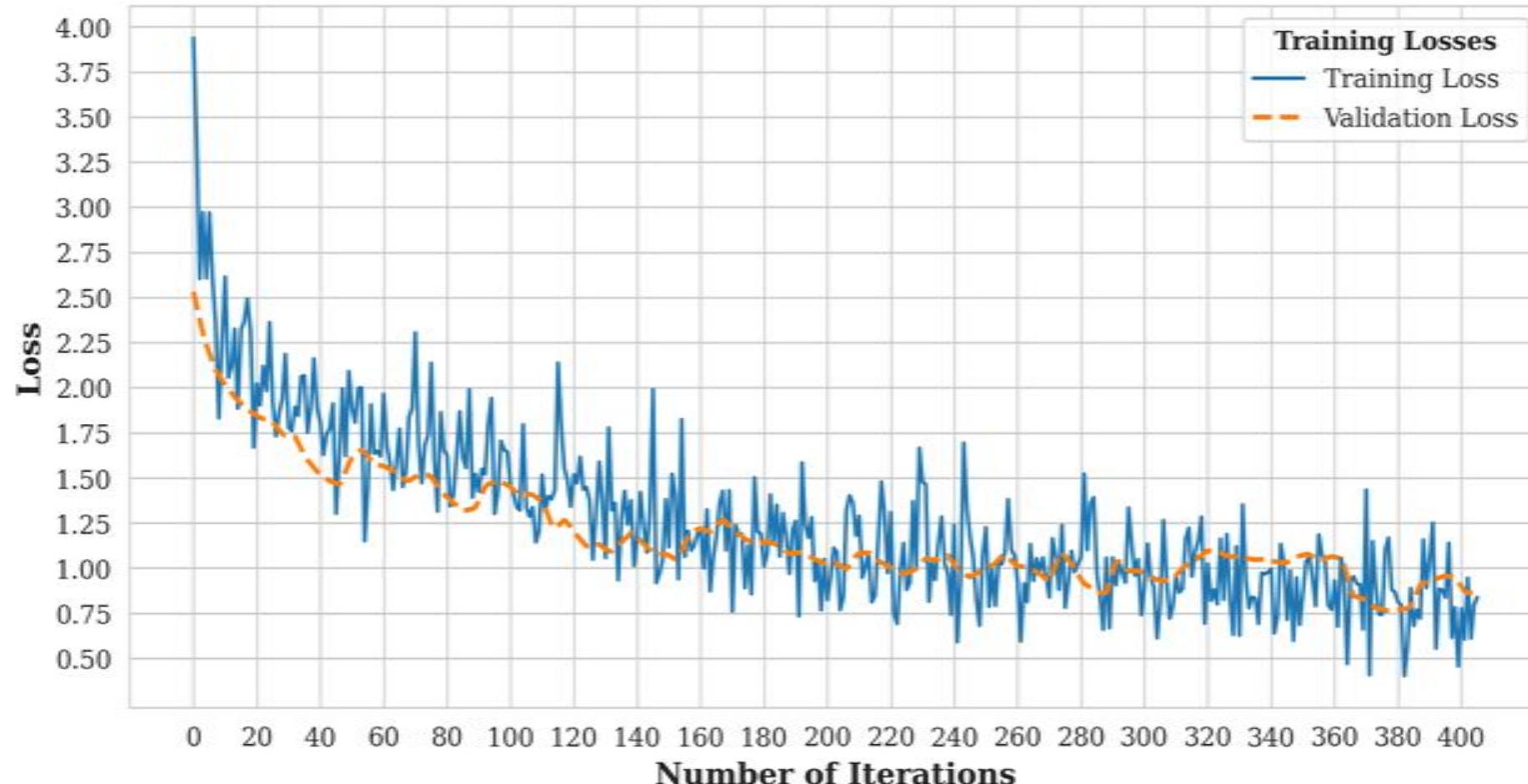
(Performance Comparison between DistilBERT & BERT)

- Although BERT outperforms, but in this comparative analysis, BERT was trained only for 2 full epochs, whereas DistilBERT was trained for 7 full epochs, biasing the results toward DistilBERT.
- Unfair analysis aside, DistilBERT, being lighter, boasts a 12-second faster average inference time and is 1 GB lighter in storage.

Datasets / Basis	Accuracy / Time	DistilBERT-based Bi-encoder Model	BERT-based Bi-encoder Model
Test Set	Average Letters Accuracy	98.73%	98.27%
	Average Words Accuracy	95.31%	94.12%
Validation Set	Average Letters Accuracy	99.72%	99.16%
	Average Words Accuracy	99.17%	96.69%
Test set	Full Puzzle Accuracy	96.37%	95.40%
Validation Set	Full Puzzle Accuracy	99.34%	97.45%
Inference Time	Average Inference Time	48.63 Seconds	61.29 Seconds
Model Size		1.48 GB	2.44 GB

Results and Analysis – [5]

(Training Vs. Validation Loss Curve)

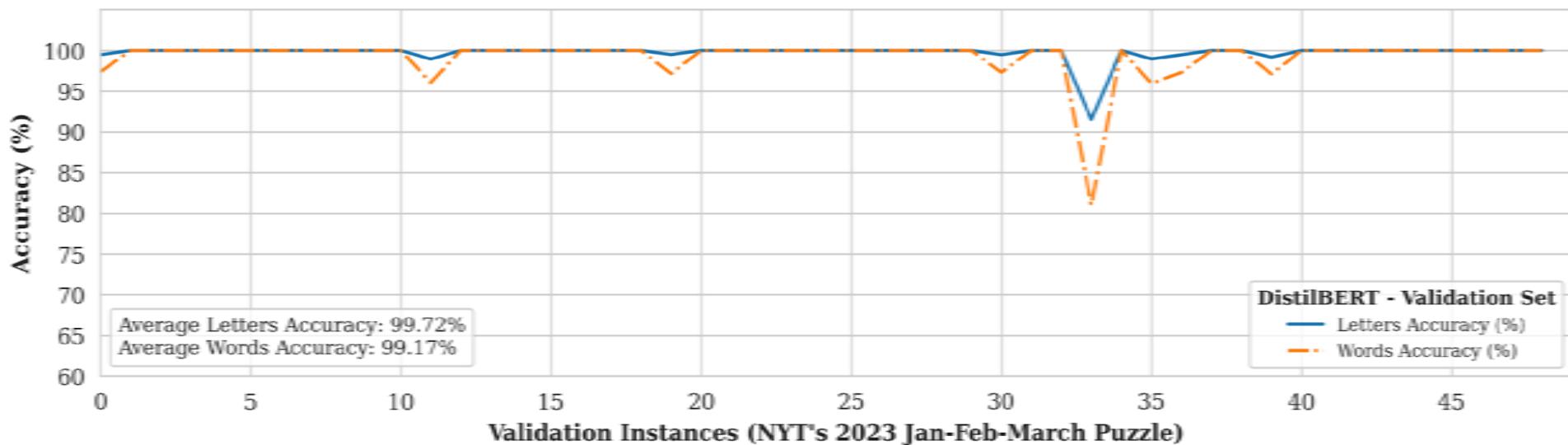
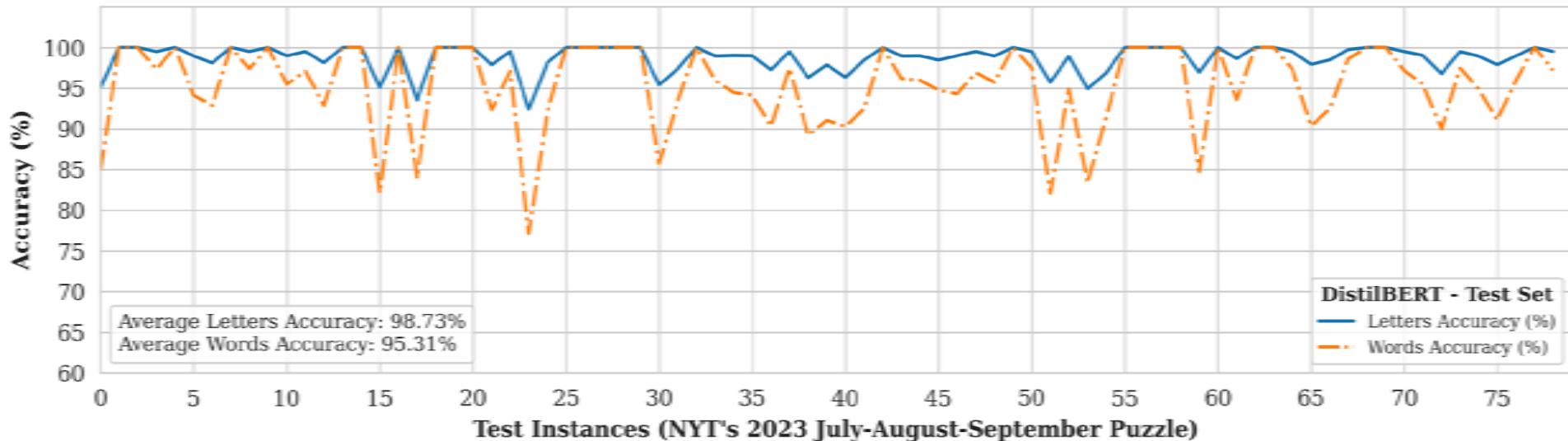


Results and Analysis – [6] (Closed-Book Model Performance Metrics)

Top-K	Recall @ k	Normalized Discounted Cumulative Gain (NDCG @ k)
Top-1	13.64%	13.30%
Top-5	30.58%	22.94%
Top-10	38.54%	27.03%
Top-100	64.98%	43.14%
Top-1000	83.49%	61.14%
Top-2000	86.85%	65.65%
Top-5000	90.63%	71.39%
Top-10000	92.76%	75.04%
Top-20000	94.65%	78.56%
Top-40000	95.98%	81.24%

- **Recall@K:** Initially lower (up to 100), but notably improves beyond 1,000, reaching a peak of 95.98% with the top 40,000 candidates, demonstrating strong recall in larger candidate pools.
- **NDCG@K:** Measures relevance of correct answers in top-k candidates; higher values imply better ranking quality and result relevance.

Results and Analysis – [7] (Crossword Solver Inference Overview)



Results and Analysis – [8]

(Candidate Answer Generation using FAISS)

S.N.	Clue	Top-5 Candidate Answers	Dot Product Score	Correct Answer	Ranked At
1	One holding all the cards	CARDDEALER	57.399	DEALER	4
		CARDEXPERT	56.505		
		CARDREADER	56.068		
		CARDHOLDER	55.857		
		DEALER	55.278		
2	London-based insurance company	LLOYDS	55.295	LLOYDS	0
		LLOYDSOFLONDON	53.115		
		LLOYDSLIST	51.472		
		MCAFEE	51.216		
		LLOYDSBRIDGES	51.059		
3	God who is destined to slay the serpent Jörmungandr	LOKI	57.029	THOR	2
		ASHUR	56.942		
		THOR	54.996		
		ODIN	54.708		
		TIU	54.254		
4	Forest giant	REDWOOD	55.185	REDWOOD	0
		GIANTREDWOODS	54.041		
		TREEBEAR	53.843		
		DAWNREDWOOD	53.803		
		CESIUMFORESTER	53.762		

Results and Analysis – [9]

(Accurate Clue Extraction Instances)

CROSSWORD

ACROSS	
1 Techniques	61 Hide-and-seek, e.g.
5 Opposite of most	62 Not much (2 wds.)
10 – accompli	63 – Barbara, Calif.
14 Without delay	64 Publicity
15 Animated chipmunk	65 El —, Texas
16 Radius neighbor	66 Point of development
17 Motion picture	67 Easy pitch
18 San Juan its capital (2 wds.)	
20 Of durable wood	
22 JAMA readers	
23 Sackers of Rome	
24 Fakes out, on the rink	
26 "It's freezing!"	
27 Flu bugs	
30 Introduce	
34 Fly by	
35 Deer mothers	
36 Sense of hearing	
37 Disembarkers	
38 Car tag	
40 Pakistan's language	
41 Moo goo — pan	
42 Androcles' pal	
43 Contradicts	
45 Fixing manuscripts	
47 Medieval clowns	
48 Dow Jones fig.	
49 Large artery	
50 Kiddie ride	
53 "Exodus" hero	
54 Inspection	
55 Ill will	
58 Half diameters	
61 Hide-and-seek, e.g.	61 Hide-and-seek, e.g.
62 Not much (2 wds.)	62 Not much (2 wds.)
63 – Barbara, Calif.	63 – Barbara, Calif.
64 Publicity	64 Publicity
65 El —, Texas	65 El —, Texas
66 Point of development	66 Point of development
67 Easy pitch	67 Easy pitch
	PREVIOUS PUZZLE SOLVED
	© 2023 UFS, Dist. by Anagram McNeil for UFS
	30 Container
	31 Chilling
	32 Auto-safety advocate
	33 Roof beam
	34 This, in Spanish
	35 Marino or Rather
	36 Town in New Mexico
	37 Folklore giants
	38 Promontory
	39 Salting away
	40 Kiddie ride
	41 Edge
	42 Helen of Troy's story
	43 Edge
	44 Promontory
	45 Large artery
	46 Edge
	47 Edge
	48 Edge
	49 Large artery
	50 Kiddie ride
	51 Edge
	52 Edge
	53 Edge
	54 Edge
	55 Edge
	56 Edge
	57 Edge
	58 Edge
	59 Edge
	60 Edge
	61 Edge
	62 Edge
	63 Edge
	64 Edge
	65 Edge

Original Image

Across	Down
1 Techniques	1 Texas town
5 Opposite of most	2 Great Wall locale
10 – accomplished	3 Jerk
14 Without delay	4 Increases in assembly line rates
15 Animated chipmunk	5 Once around a track
16 Radius neighbor	6 Avoids capture
17 Motion picture	7 Says decidedly
18 San Juan is its capital @ wds.)	8 Gentlemen
20 Of durable wood	9 Cable channel
22 JAMA readers	10 Commotions
23 Sackers of Rome	11 Landed
24 Fakes out, on the rink	12 Rainfall measure
26 "It's freezing!"	13 Town in New Mexico
27 Flu bugs	19 Folklore giants
30 Introduce	21 Promontory

Extracted clues

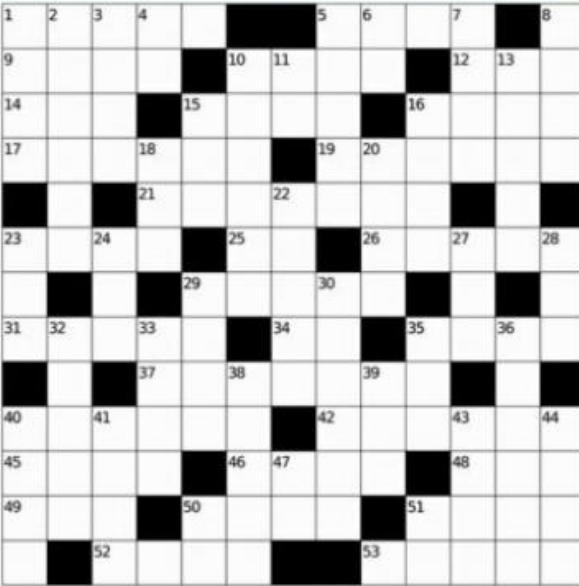
Results and Analysis – [10] (Failed Clue Extraction Instances)

ACROSS

- Toss
- Jail
- Precipitation
- Leap
- Kangaroo
- Assist
- Tam
- Knave
- Stylish
- Affects emotion
- Commander in chief of a fleet
- Verse
- Part of the verb "to be"
- Lack of tone
- Remove weapons from
- Moues
- Depart
- Performs
- Discloses
- Species
- Go over old ideas
- Foot of a horse
- Monetary unit of Angola
- Atomic mass unit
- Abstract being
- Bound
- Grain husk
- Head covering
- Walls

DOWN

- Type of jazz
- Coufure
- Travel on
- Not off
- Rum
- Toward the top
- Minor oath
- Chinese cooking implements
- One of the latty
- Satisfactory
- Large body of water
- Hallucinogenic drug
- Rough bump
- Uncle -, USA personified
- Madam
- Icon
- Nipple
- Australian bird
- Mythical sea monster
- Affirmative response
- Consumer
- Screamed



SOLUTION:



Original Image

Across

3 screamed ie fo | i a
15 rotcropere
68 h ei artd a
2 phrtott so.lnthe recon
of si tos thro wmo uo ow
ral nicu pmr 00 at omuak
em ack dress ymiemotes
bomsomi es mall poe
mma mma tony
32 . greek eave
23 nothoster
33 freremans
36 dutch ate
38 . gonos
40 chases 'ater
4 food baker con
seatzetand
44 vandals
0 en pour silic omma cts
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ramir ewa sh. hoo empl
wwe lia mu ensmit | colle

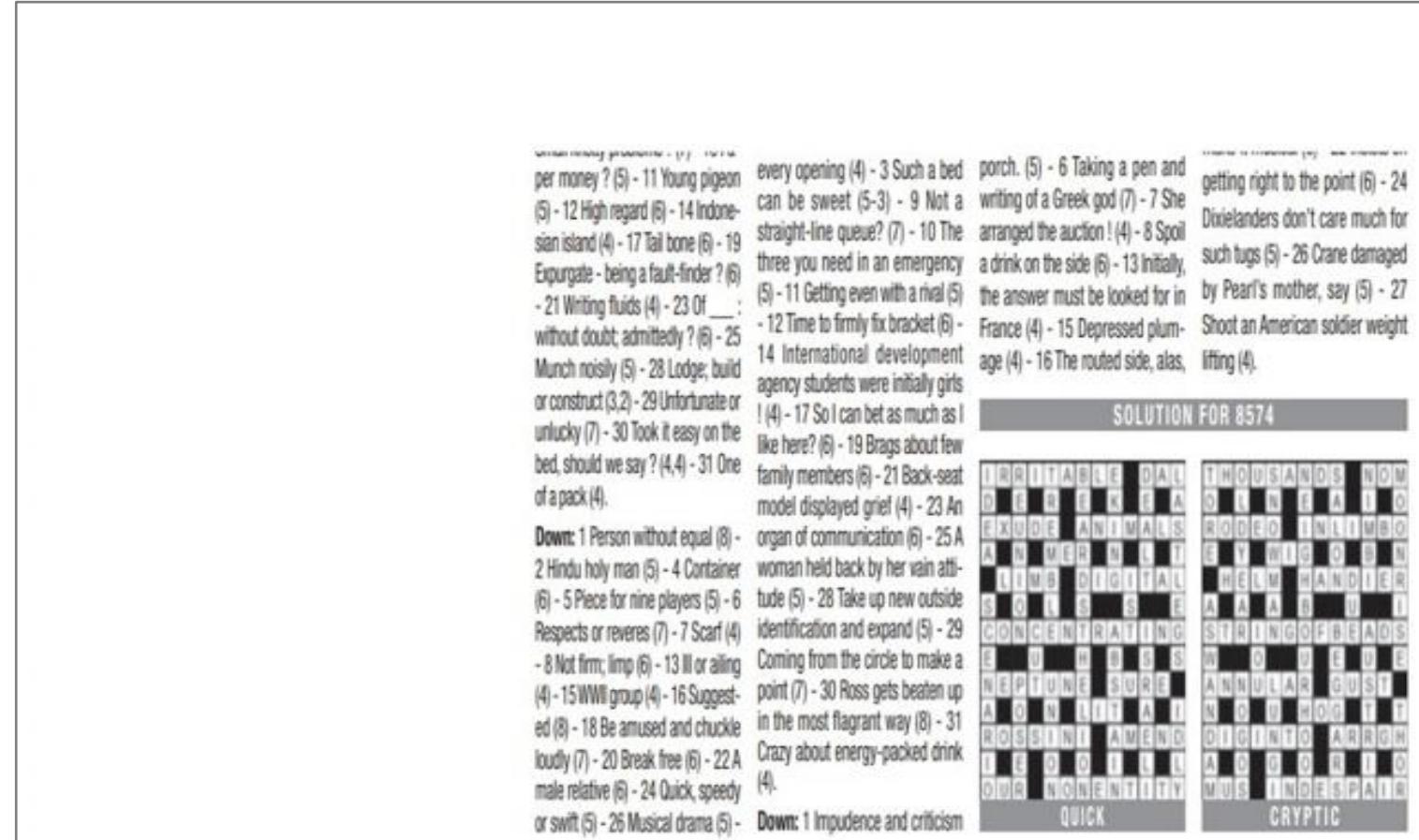
Down

Extracted clues

Results and Analysis – [11] (Errors in Clues Extraction)

74. Medieval helmet	29.
75. -- Nell McEntire	32.
76. Edible tuber	33.
77. Jumped	35.
78. Meddles	36.
79. Ague	37.
80. Reasoner's word	38.
81. Soft drinks	40.
82. Roadside establishments	41.
83. Cal. abbr.	42.
86. Expert	43.
87. Singer Fitzgerald et al.	44.
88. Deadly gas	46.
89. Refugee relative	47.
91. "--- for the Misbegotten"	48.
92. Vienna resident	50.
95. --- Adventist	51.
97. Intuitive ability: 2 wds.	52.
99. Banded quartz	53.
100. "Garfield" dog	54.
101. Like a lot	55.
102. External: Prefix	56.
103. Leafy course	
104. Hairless	57.
105. Echo sounder	58.
106. Hebrew letter	59.

Impact of Small Tab Stop Width



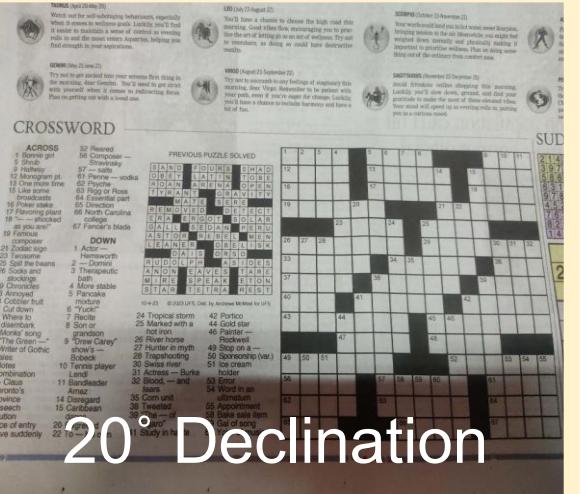
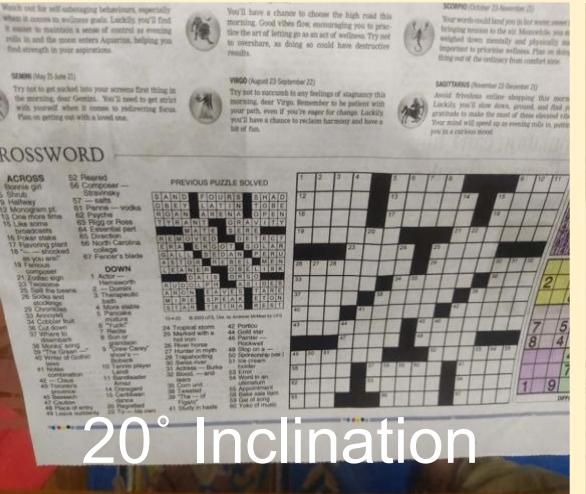
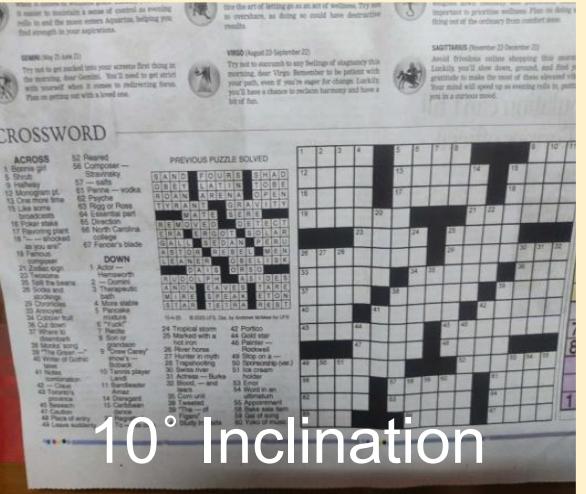
Crossword Formatting Challenges

Results and Analysis – [12] (Errors in Clues Extraction)

Across	38	Car tag	car tag	Down	29	Half diameters	half diameters
	40	Pakistan's language	pakistan's language		30	Container	Container
	41	Moo goo — pan	moo 960 — pan		31	Chilling	Chilling
	42	Androcles' pal	androcles' pal		32	Auto-safety advocate	auto-safety advocate
	43	Contradicts	contradicts		33	Roof beam	roof beam
	45	Fixing manuscripts	fixing manuscripts		35	Marino or rather	marino or rather
	47	Medieval clowns	medieval clowns		39	Ship's record	ship's record
	48	Dow jones fig.	dow jones fig.		40	Lacking education	lacking education
	49	Large artery	laane artery		44	This,in Spanish	this, in Spanish
	50	Kiddie ride	kiddie ride		46	Become fond of (2 wds.)	become fond of iS (wds)
	53	“Exodus” hero	“exodus” hero		47	Cheap nightclubs	cheap nightclubs
	54	Inspection	Inspection		49	Basketball Venue	?
	58	Ill will	ill will		50	Catch	?

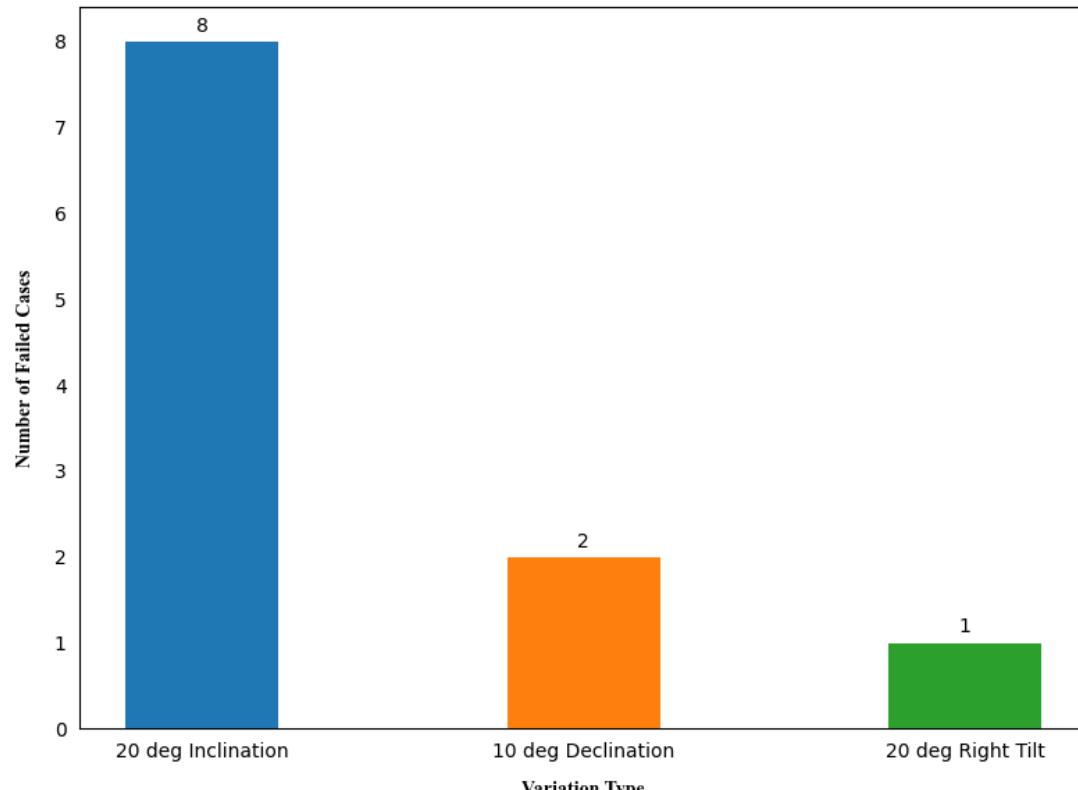
Challenges in Complete Text Detection

Results and Analysis – [13] (Input Variations)

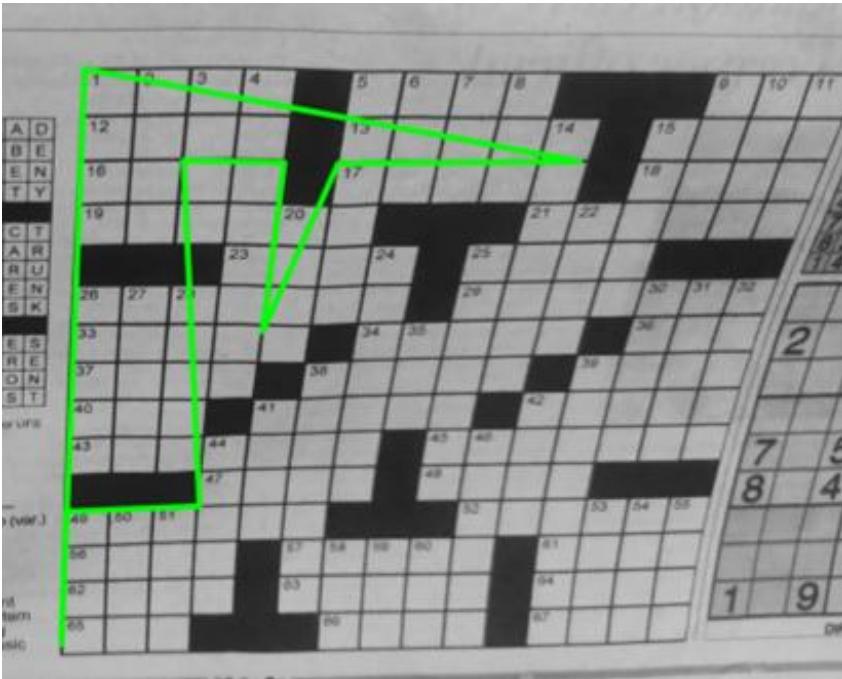


Results and Analysis – [14] (Grid Extraction Performance)

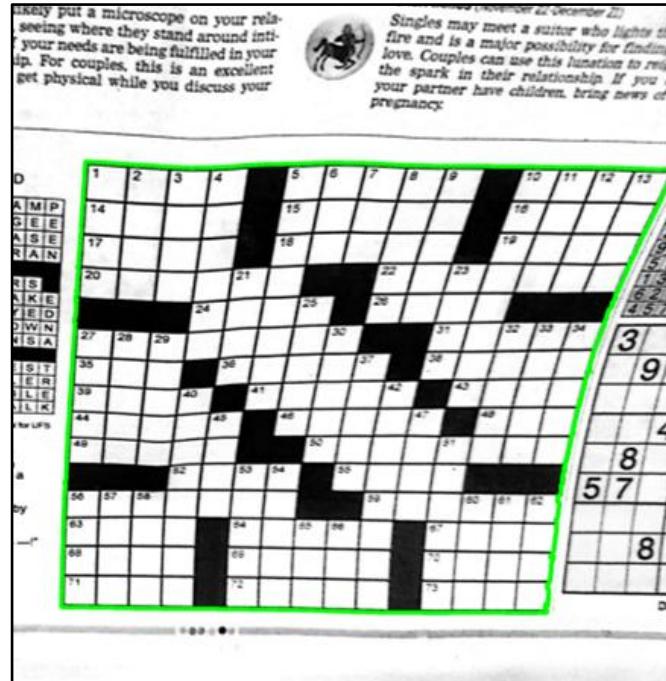
- Accuracy of pipeline was tested on 16 different images.
- 128 images were obtained by varying each image as follows:
 - Straight orientation
 - 10 degrees right tilt
 - 20 degrees right tilt
 - 10 degrees left tilt
 - 20 degrees left tilt
 - 10 degrees inclination
 - 20 degrees inclination
 - 10 degrees declination
- Success rate of 86% was achieved
- Grid Extraction failed on 11 images



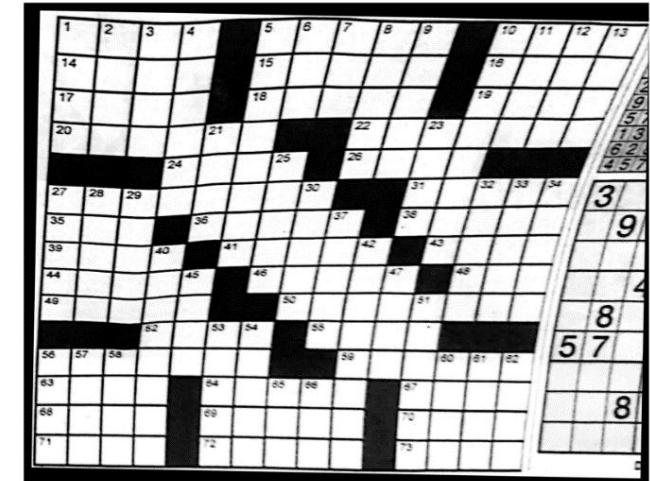
Results and Analysis – [15] (Failed Grid Extraction Instances)



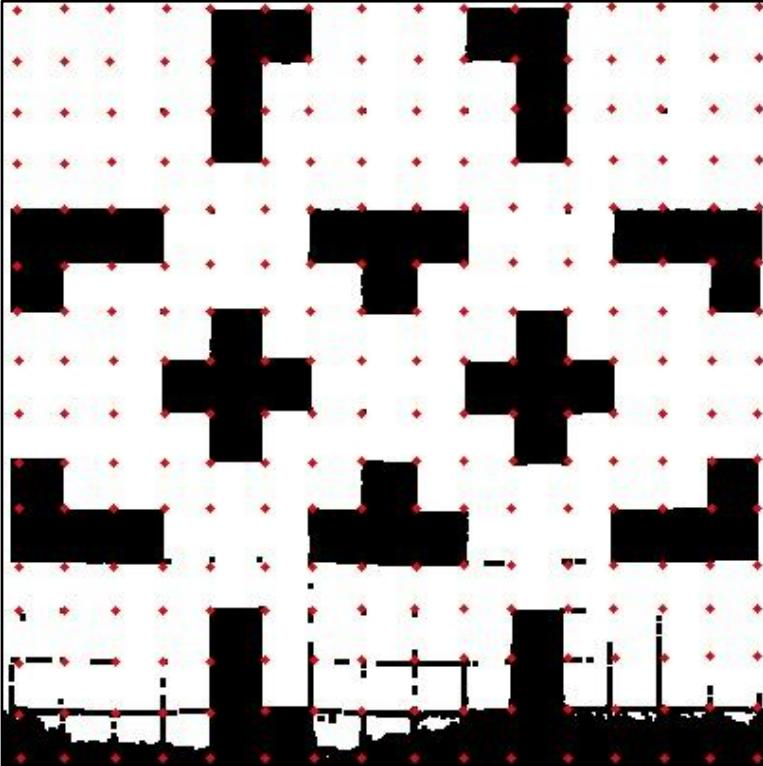
Failed Contour Detection



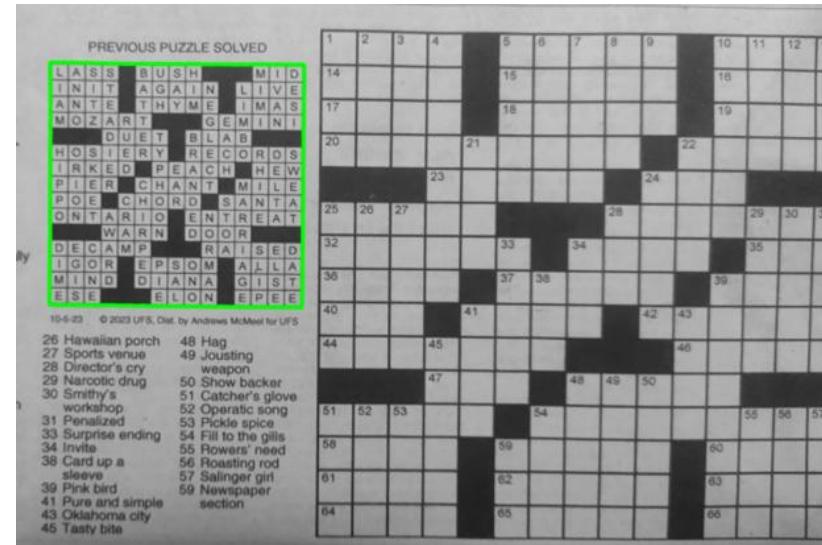
Failure Due to Curves and Creases in
Newspaper



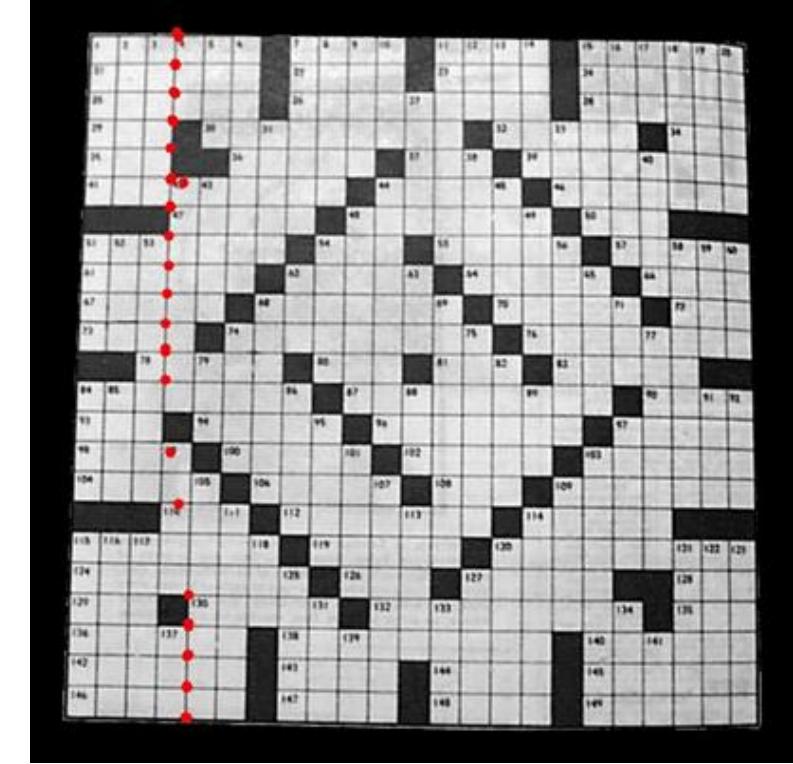
Results and Analysis – [16] (Errors in Grid Extraction)



Error In Binarization



Wrong Contour Selection



Incorrect Corner Grouping

Results and Analysis – [17] (Accurate Grid Extraction Instances)

CROSSWORD

ACROSS

- Techniques
- Opposite of most
- Without delay
- Animated chipmunk
- Radius neighbor
- Motion picture
- San Juan is its capital (2 wds.)
- Of durable wood
- JAMA readers
- Sackers of Rome
- Fakes out.
- Texas town
- Great Wall locale
- Jerk
- Increases in assembly line rates
- Once around a track
- Avoids capture
- Says decidedly
- Gentlemen
- Cable channel
- Commotions
- Moō goo — pan
- Androcles' pal
- Contradicts
- Fixing
- manuscripts
- Medieval clowns
- Dow Jones fig.
- Large artery
- Kiddie ride
- "Exodus" hero
- Inspection
- Ill will
- Half diameters

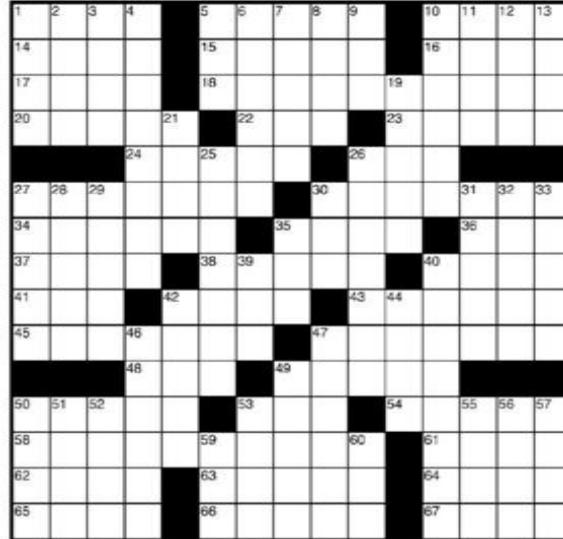
DOWN

- "It's freezing!"
- Flu bugs
- Introduce
- Fly by
- Deer mothers
- Sense of hearing
- Disembarks
- Car tag
- Pakistan's language
- Moō goo — pan
- Androcles' pal
- Contradicts
- Fixing
- manuscripts
- Medieval clowns
- Dow Jones fig.
- Large artery
- Kiddie ride
- "Exodus" hero
- Inspection
- Ill will
- Half diameters

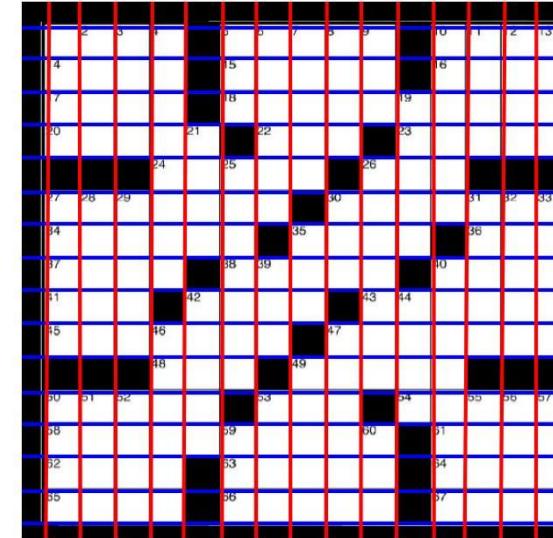
6-19-25 © 2023 UFS, Dist. by Anonine McMenin for UFS

PREVIOUS PUZZLE SOLVED

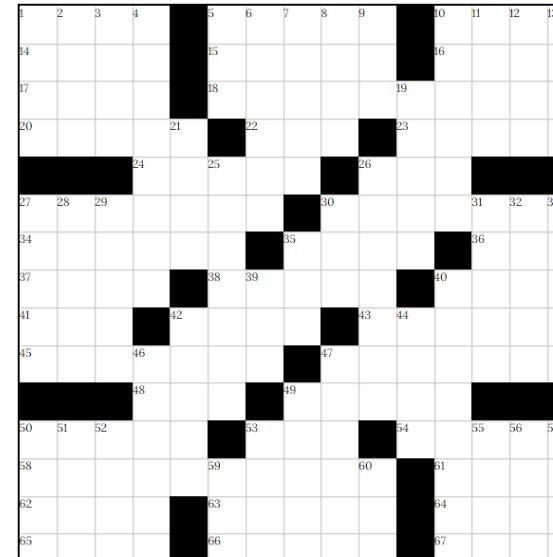
C	H	E	R	S	C	R	A	P	O	M	E	N
62	Not much	(2 wds.)										
63	Barbara,	Calif!										
AUDI	COUPE	YUMA										
BEEP	OPERA	STIR										
SNOOPED	LATELY											
FLED	CEDE											
CAFE'S	LITTER											
GESSO	OATH	SLOB										
ALL	ABBEY	EMU										
STAG	LOOM	FLAIR										
OILER	JOINT											
PLOT	YOGA											
DROIDS	KISSING											
EIRE	ADEPT	SOAP										
ADDS	REPELL	OSLO										
FEST	ANISE	NEAP										



Scanned Image



Approximated Grid
Borders

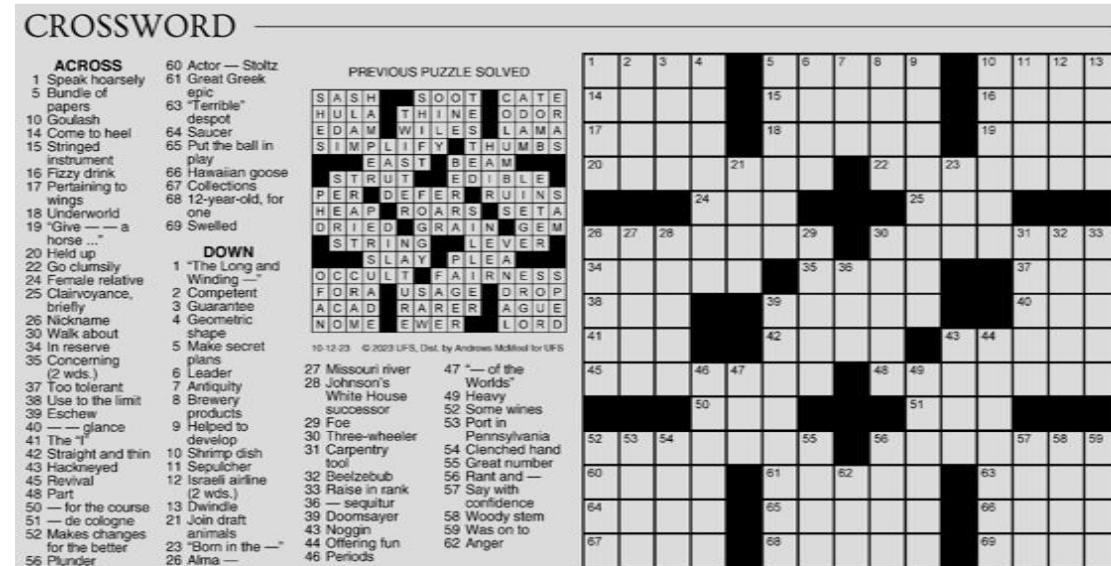


Final Digitized Grid

Results and Analysis – [18] (GUI Interface)

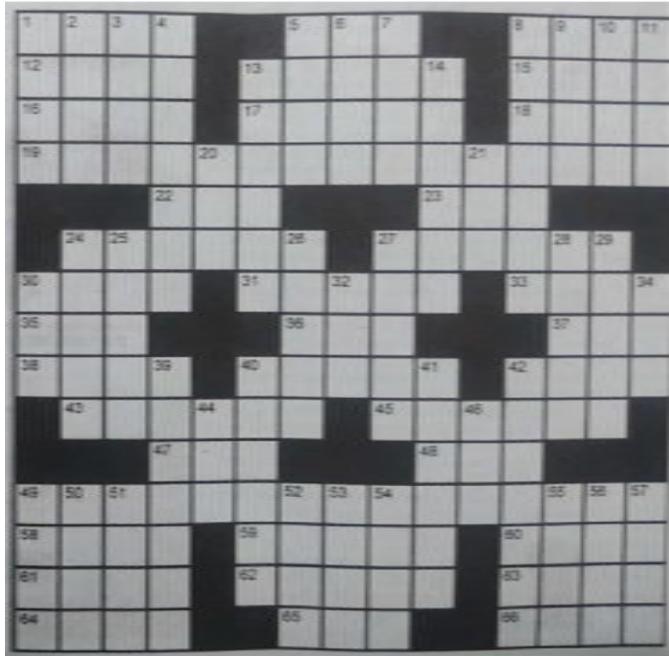
The screenshot shows the EZ-Crossword website's home page. At the top, there is a navigation bar with links for Home, Solver, Generator, and About-Us. Below the navigation bar, the text "Solve Crosswords Using AI." and "Upload Files to Get Started." is displayed. To the left, there is a decorative graphic featuring a person holding a pencil over a crossword grid. On the right, there is a large blue-bordered box containing a file upload interface with the text "Drop files here" and "Choose File" buttons, and a file path "scanned-1.jpg". At the bottom of the page, there is a copyright notice: "© 2023 Team TimTim. All rights reserved."

File Uploading Interface

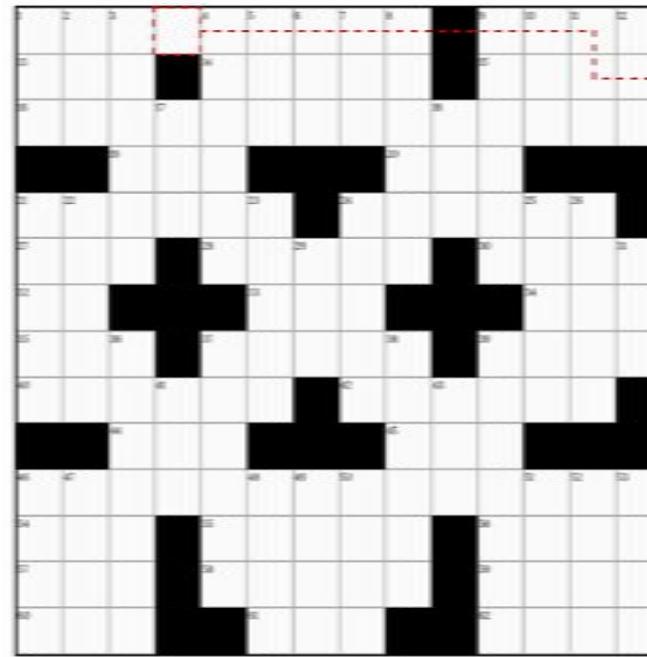


A Crossword Snapshot from
'The Kathmandu Post' –
October 1st, 2023

Results and Analysis – [19] (GUI Interface)

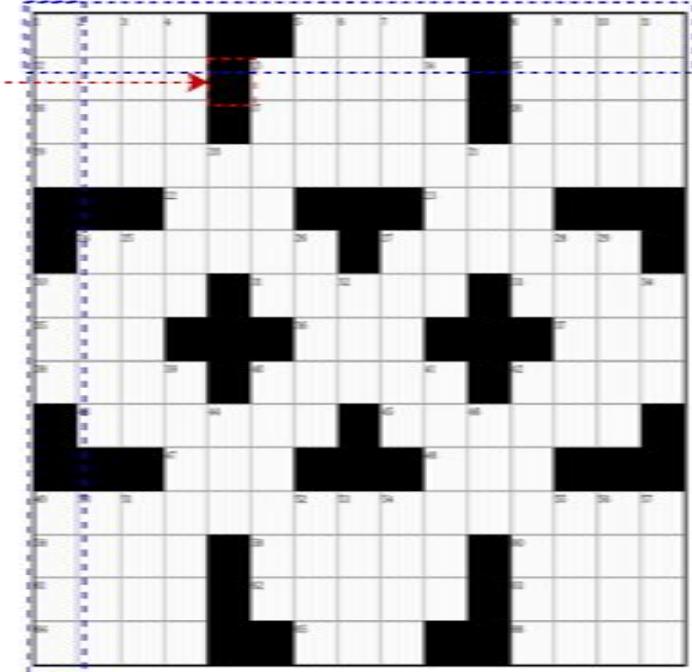


Input Image



Digitized Grid Without Correction

- 14 X 14 + ⌂ Rotate 90° C D



Grid After Correction

- 15 X 15 + ⌂ Rotate 90° C D

Results and Analysis – [20] (GUI Interface)

The image displays two side-by-side screenshots of the EZ-Crossword application's "Solver" tab. Both screens show a 15x15 crossword grid with blacked-out squares for empty cells. A red dashed box highlights a specific set of entries in both lists.

Left Screen (Clues Before Correction):

- Across:** 1, 5, 10, 14, 15, 16, 17, 18, 19, 20, 22, 24, 25, 26, 28, 29, 30.
- Down:** 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30.

Right Screen (Clues After Correction):

- Across:** 1, 5, 10, 14, 15, 16, 17, 18, 19, 20, 22, 24, 25, 26, 28, 29, 30.
- Down:** 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 23, 24, 25, 26, 27, 28, 29, 30.

A red dashed box highlights the following entries in both lists:

- Across: Clue 1 (15) and Clue 5 (15).
- Down: Clue 5 (15), Clue 6 (15), Clue 14 (15), Clue 21 (15), Clue 23 (15), Clue 24 (15), Clue 25 (15), Clue 26 (15), Clue 27 (15), Clue 28 (15), Clue 29 (15), and Clue 30 (15).

Clues Before Correction

Clues After Correction

Results and Analysis – [21] (GUI Interface)

EZ-Crossword

Home Solver Generator About-Us

Puzzle Solution

Solve Next

The screenshot shows a crossword puzzle grid with various words filled in. To the right of the grid is a table listing the solved words, categorized into Across and Down. The Across section lists words like RASPBERRY, CELESTIAL, ALARUM, DELAYED, MOMENT, MONIKER, ASIDE, TAX, AVOID, EGOMANIA, RENEWAL, PARADE, REFORMS, ERIC, DISH, and SETS. The Down section lists words like REVIVAL, PART, COURSE, HADES, MAN, STUMBLE, ESPRESSO, KERASIA, PLUNDER, TAXI, AVOID, LANK, BANANA, ELEMENT, EAU, RENEWAL, PARADE, REFORMS, ERIC, DISH, and SETS.

Across	Down
RASPBERRY	REVIVAL
CELESTIAL	PART
ALARUM	COURSE
DELAYED	HADES
MOMENT	MAN
MONIKER	STUMBLE
ASIDE	ESPRESSO
TAXI	KERASIA
AVOID	PLUNDER
EGOMANIA	TAXI
RENEWAL	AVOID
PARADE	LANK
REFORMS	BANANA
ERIC	ELEMENT
DISH	PA
SETS	REFORMS

Solver Generated Solution



Newspaper Provided Solution

Remaining Tasks

- Refining Grid Extraction Pipeline
- Refining Clue Extraction Pipeline
- Training QA model on complete dataset
- Grid Filling with Constraint Resolution
- Completing the web application
- Developing Crossword Generation

References – [1]

- C. Agarwal and R. K. Joshi, "Automation Strategies for Unconstrained Crossword Puzzle Generation," arXiv, 2020. [Online]. Available: arXiv:2007.04663v1.
- ALBERT: A Lite BERT for Self-supervised Learning of Language Representations," arXiv, 09 02 2020. [Online]. Available: arXiv:1909.11942v6.
- S. Humeau, K. Shuster, M. A. Lachaux and J. Weston, "Poly-encoders: Transformer Architectures and Pre-training Strategies for Fast and Accurate Multi-sentence Scoring," CoRR, vol. abs/1905.01969, 2019.
- D. Bonomo, A. P. Lauf and R. Yampolskiy, "A crossword puzzle generator using genetic algorithms with Wisdom of Artificial Crowds," in 2015 Computer Games: AI, Animation, Mobile, Multimedia, Educational and Serious Games (CGAMES), 2015, pp. 44-49}
- M. Lewis, Y. Liu, N. Goyal, M. Ghazvininejad, A. Mohamed, O. Levy, V. Stoyavnov and L. Zettlemoyer, "BART: Denoising Sequence-to-Sequence Pre-training for Natural Language Generation, Translation, and Comprehension," 29 8 2019. [Online]. Available: arXiv:1910.13461.
- J. Bromley, J. W. Bentz, L. Bottou, I. Guyon, Y. Lecun, C. Moore, E. Sackinger and R. Shah , "Signature Verification using a "Siamese" Time Delay Neural Network," International Journal of Pattern Recognition and Artificial Intelligence, vol. 7, p. 25, 1993

References – [2]

- M. Littman, G. Keim and N. Shazeer, "A probabilistic approach to solving crossword puzzles," *Artificial Intelligence*, vol. 134, pp. 23-55, 2001.
- M. Ernandes, G. Angelini and M. Gori, "WebCrow: a WEB-based system for CROssWord solving," *AAAI*, 2005.
- M. L. Ginsberg, "Dr.Fill: Crosswords and an Implemented Solver for Singly Weighted CSPs," *ArXiv*, vol. abs/1401.4597, 2011.
- T. Gammedda and M. G. N. A. S. Fernando, "End-to-End Automated Crossword Solver using Image Processing, Natural Language Processing and Neural Network," in *2022 2nd International Conference on Advanced Research in Computing (ICARC)*, 2022, pp. 43-48.
- E. Wallace, N. Tomlin, A. Xu, K. Yang, E. Pathak, M. L. Ginsberg and D. Klein, "Automated Crossword Solving," *ArXiv*, 2022.
- J. Devlin, M.-W. Chang, K. Lee and K. Toutanova, "BERT: Pretraining of Deep Bidirectional Transformers for Language Understanding," 2019. [Online]. Available: [arXiv:1810.04805](https://arxiv.org/abs/1810.04805).

Thank You!