

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

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7th March, 2024

Presentation Outline

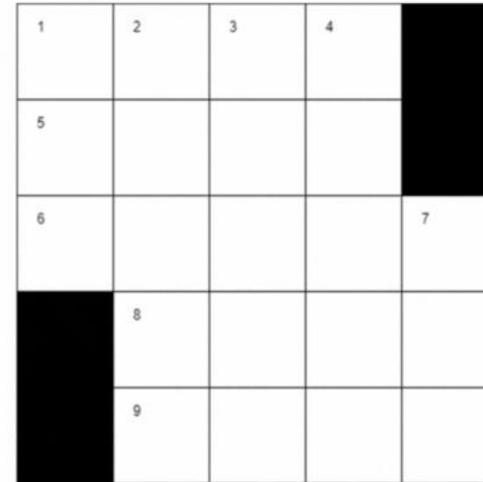
- Motivation
- Project Objectives
- Scope of Project
- Project Application
- Crossword Rules
- Methodology
- Results and Analysis
- Future Enhancements
- Conclusion
- Project Budget
- Project Schedule
- References

Motivation

Challenges in Crossword Solving

Benefits of Crossword Solving

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



ACROSS	DOWN
<ol style="list-style-type: none">1. Shivering feeling5. Solo performance6. Kitchen furniture8. Alteration of hair9. Murder	<ol style="list-style-type: none">1. Household animal2. Verbal assessments3. Defamation of a person4. A vibrant flower7. Common noun suffix

Problem Statement

- Lack of diverse tools that facilitate effortless crossword solving and generation.
- Existing tools are limited, lacking support for diverse styles and custom grid creation.

Objectives

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

Scope of Project

Project Capabilities:

- Crossword Solver for American & British styled crossword problems
- Utilizes computer vision techniques to solve crossword from images
- Crossword Generator generates American & British styled puzzles with varying grid size

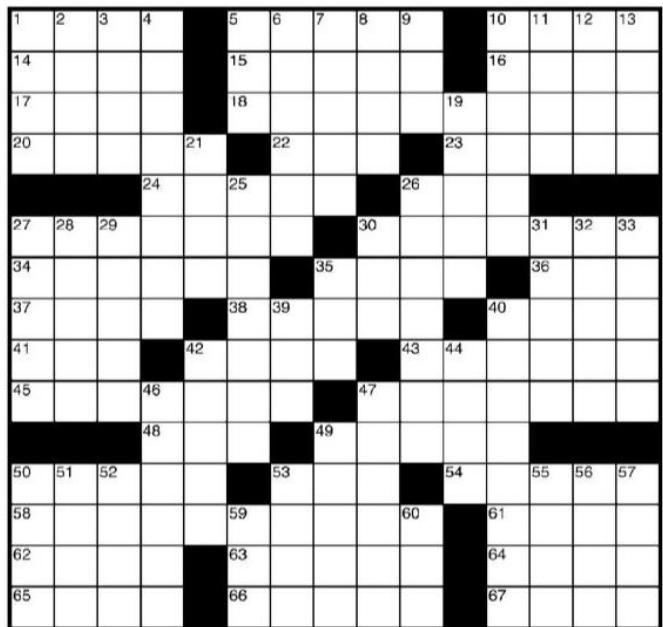
Project Limitation:

- Limited to English language crossword solving and generation
- Both the puzzle solver and editor support only American & British styled crosswords
- Crossword Generator faces challenges in filling the grid while generating crossword puzzles with larger grid sizes and answer lengths

Project Applications

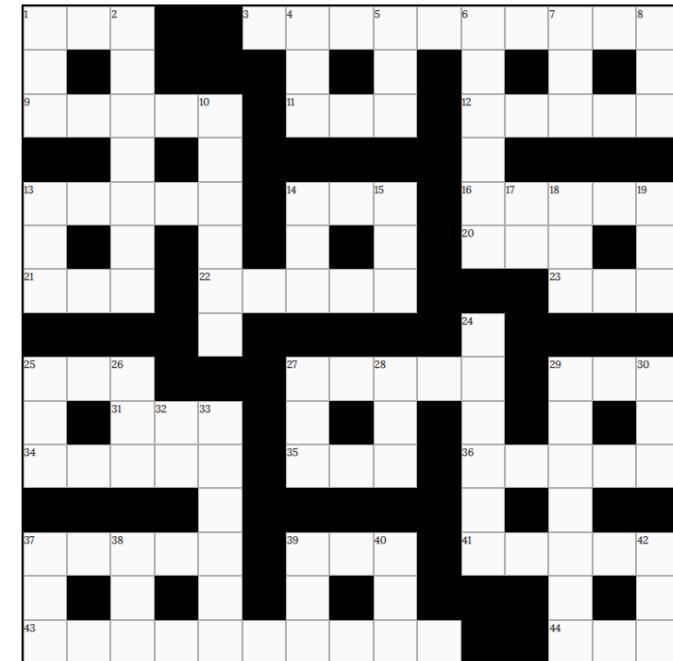
- Crossword Puzzle Aid
 - Helps solve and generate challenging crossword clues.
- Puzzle Analysis and Trend Tracking
 - Analyzes trends in puzzles and clues from puzzle archives
- Educational Puzzle Tool
 - Reinforces learning through interactive crosswords
- Language Learning Tool
 - Expands vocabulary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

Crossword Rules



American-Styled Crossword

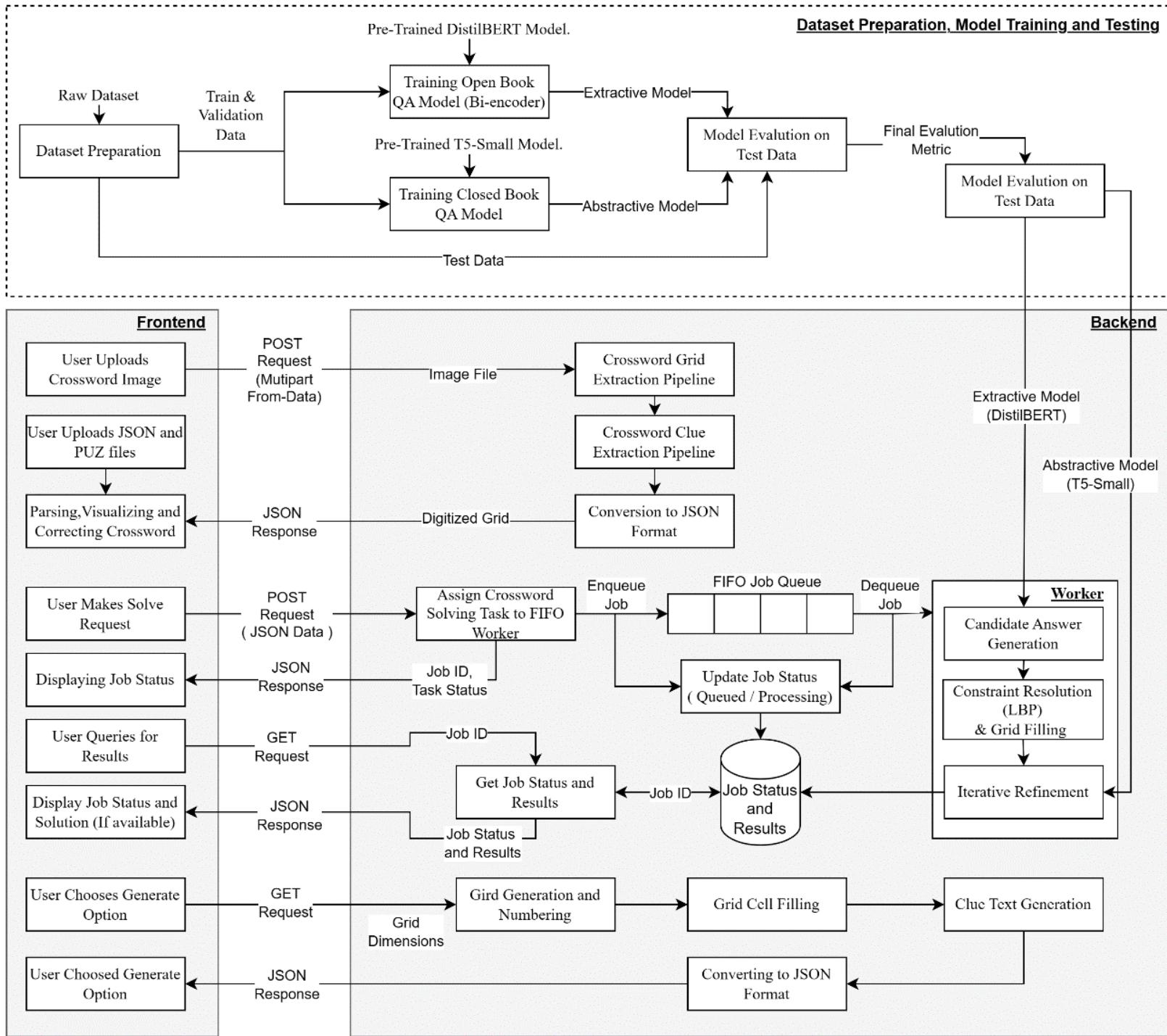
S.N.	Rules
1	The grid has 90° or 180° rotational symmetry.
2	The grid is a square, typically with odd dimensions.
3	The words in the grid should interlock with each other (Alternatively for British Crosswords).
4	The number of black squares is generally limited to $1/6^{\text{th}}$ of the grid on the upper end ($1/3^{\text{rd}}$ to $1/4^{\text{th}}$) for British Crosswords).
5	American crosswords usually have a theme.



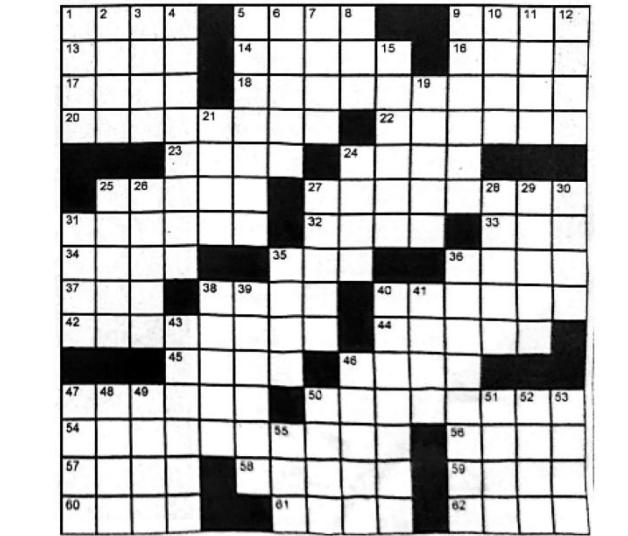
British-Styled Crossword

Methodology - [1] (System Block Diagram)

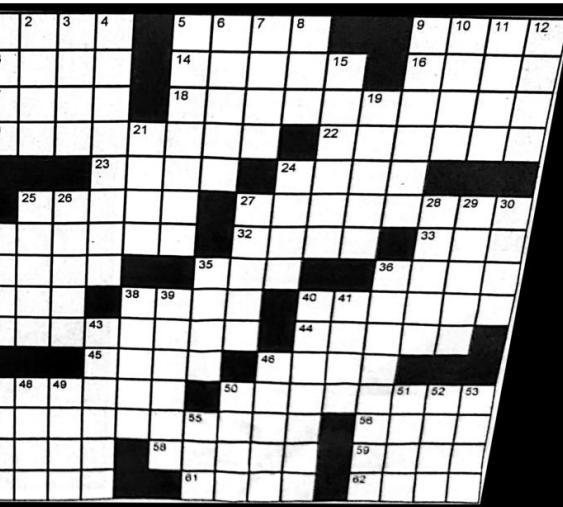
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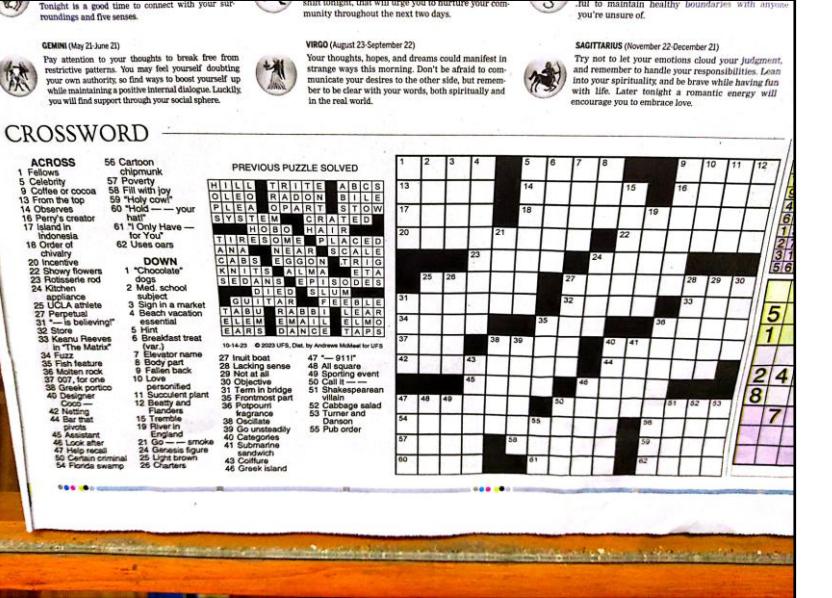
Methodology - [2] (Crossword Data Input Pipeline)



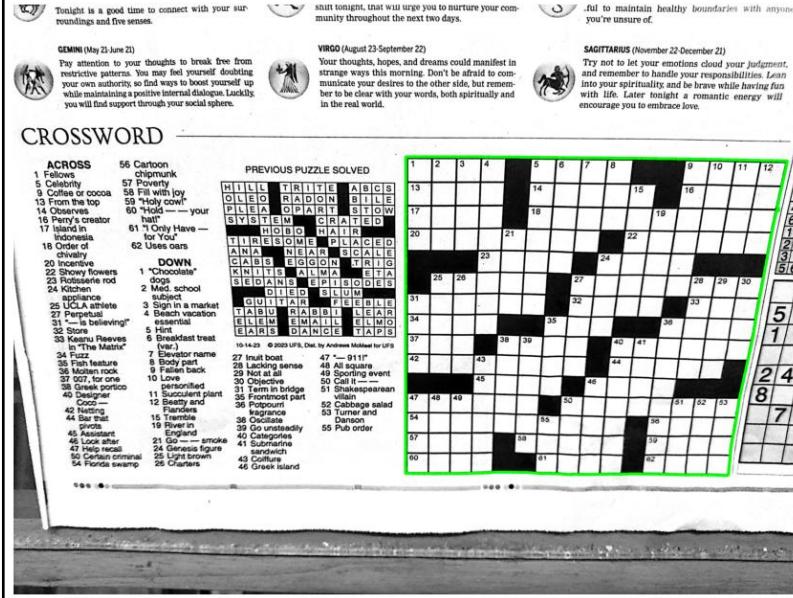
Perspective Transformed Image



Extracted Grid Image

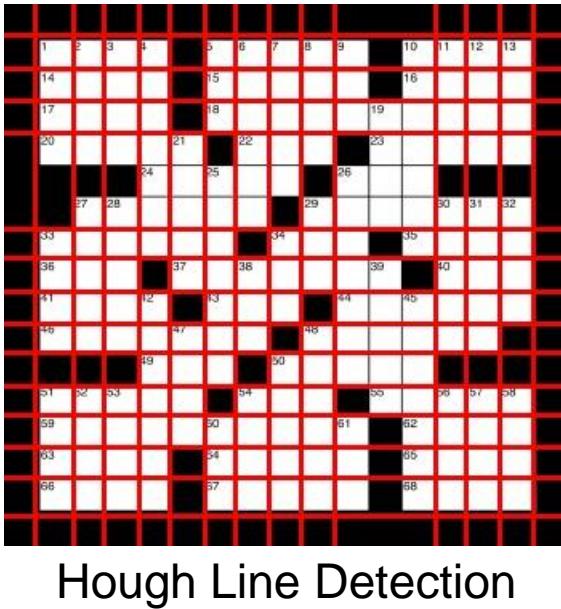


Original Image

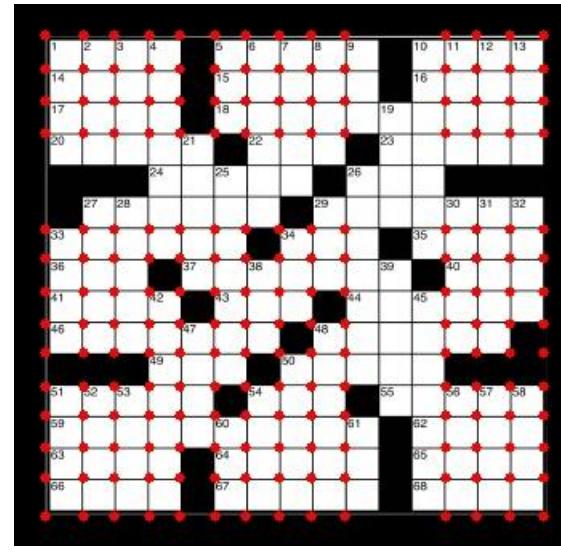
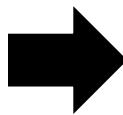


Largest Contour Detection

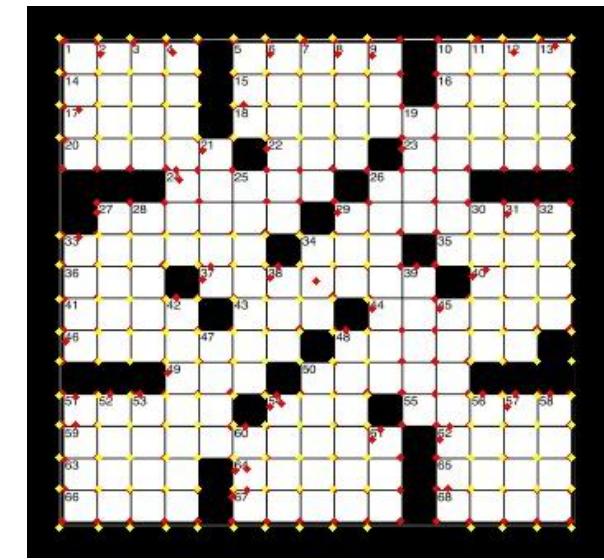
Methodology - [3] (Crossword Data Input Pipeline)



Hough Line Detection

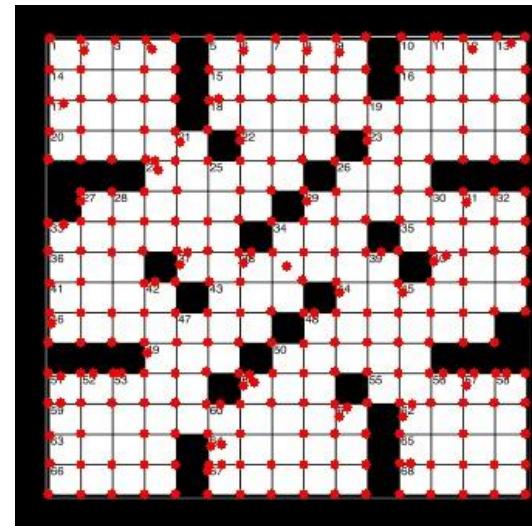
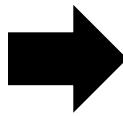


Intersection Points



Combined Corners

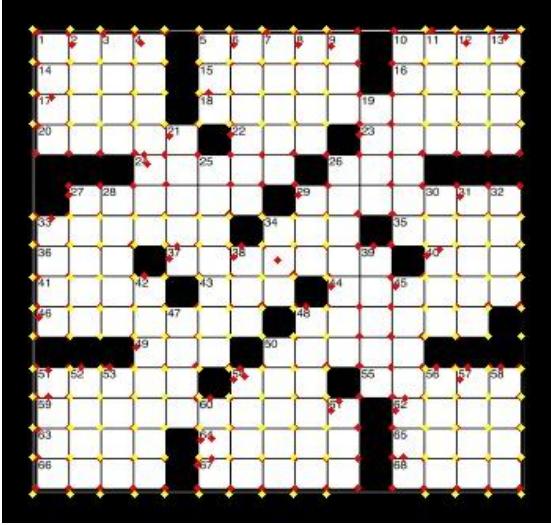
CLAHE Image



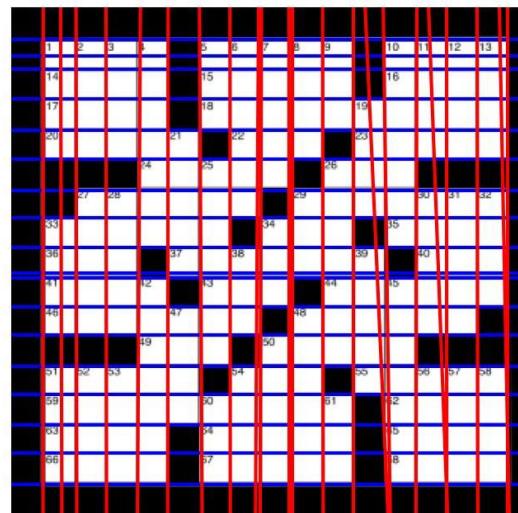
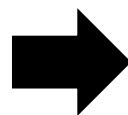
Harris Corner Detection



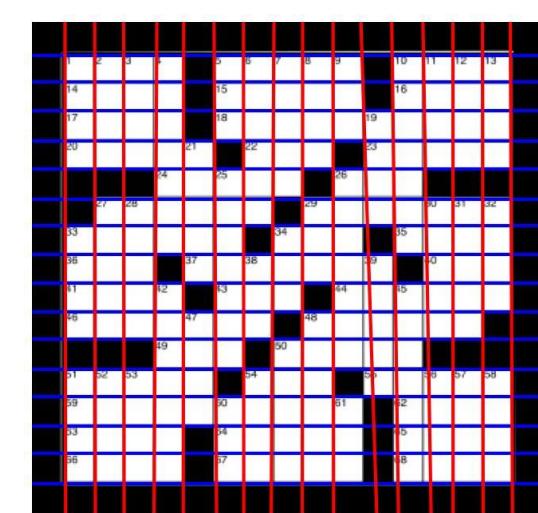
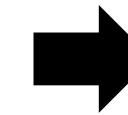
Methodology - [4] (Crossword Data Input Pipeline)



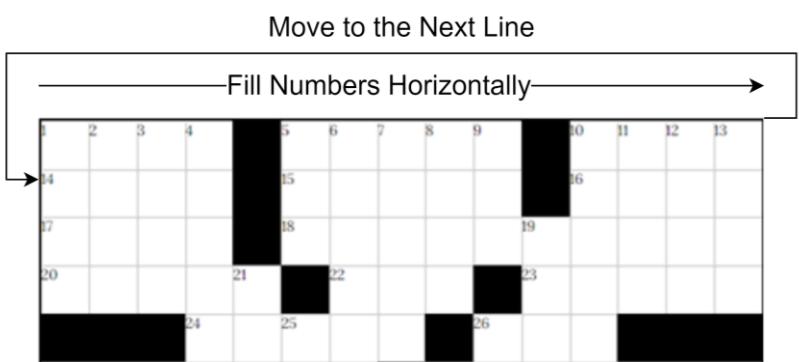
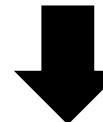
Combined Corners



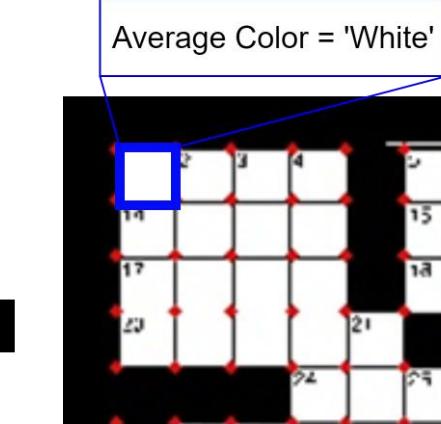
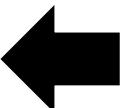
Fitting Regression Lines



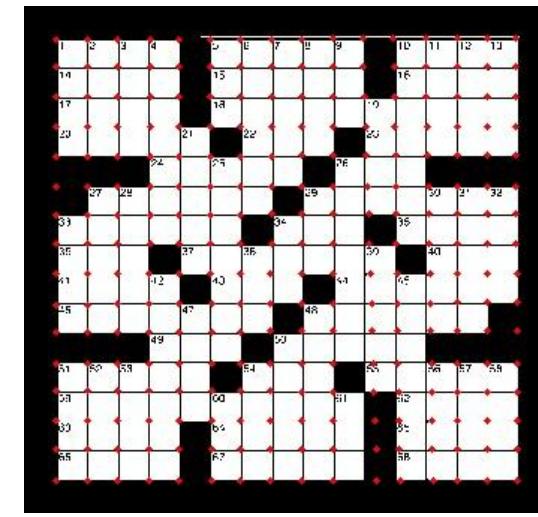
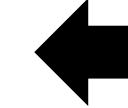
Filtered Regression Lines



Cell number computation
using grid color information



Cell color extraction by
computing average pixel
value



Approximated Cell Borders

Methodology - [5] (Clue Extraction)

Clues Image

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	65 El —, Texas
chipmunk	66 Point of development
16 Radius neighbor	67 Easy pitch
17 Motion picture	
18 San Juan is its capital (2 wds.)	
20 Of durable wood	
22 JAMA readers	
23 Sackers of Rome	
24 Fakes out, on the rink	1 Texas town
26 "It's freezing!"	2 Great Wall locale
27 Flu bugs	3 Jerk
30 Introduce	4 Increases in assembly line rates
34 Fly by	5 Once around a track
35 Deer mothers	6 Avoids capture
36 Sense of hearing	7 Says decidedly
37 Disenclumbers	8 Gentlemen
38 Car tag	9 Cable channel
40 Pakistan's language	10 Commotions
41 Moo goo — pan	11 Landed
42 Androcles' pal	12 Rainfall measure
43 Contradicts	13 Town in New Mexico
45 Fixing manuscripts	19 Folklore giants
47 Medieval clowns	21 Promontory
48 Dow Jones fig.	25 Salting away
49 Large artery	26 Puppy seller
50 Kiddie ride	27 Edge
53 "Exodus" hero	28 Helen of Troy's story
54 Inspection	29 Half diameters
58 Ill will	30 Container
	31 Chilling
	32 Auto-safety
	33 Roof beam
	35 Marino or Rather
	39 Ship's record
	40 Lacking
	42 Perk up
	44 This, in Spanish
	46 Become fond of (2 wds.)
	47 Cheap nightclubs
DOWN	
1 Techniques	49 Basketball venue
5 Opposite of most	50 Catch
10 — accompli	51 "Fancy" singer
14 Without delay	52 Egyptian goddess
15 Animated	53 Bombay nanny
chipmunk	55 The Banana Boat Song (hyph.)
16 Radius neighbor	56 Scamps
17 Motion picture	57 Kickoff stands
18 San Juan is its capital (2 wds.)	59 Recipe amt.
20 Of durable wood	60 Menlo Park initis.
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 Disenclumbers	
38 Car tag	
40 Pakistan's language	
41 Moo goo — pan	
42 Androcles' pal	
43 Contradicts	
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47 Medieval clowns	
48 Dow Jones fig.	
49 Large artery	
50 Kiddie ride	
53 "Exodus" hero	
54 Inspection	
58 Ill will	

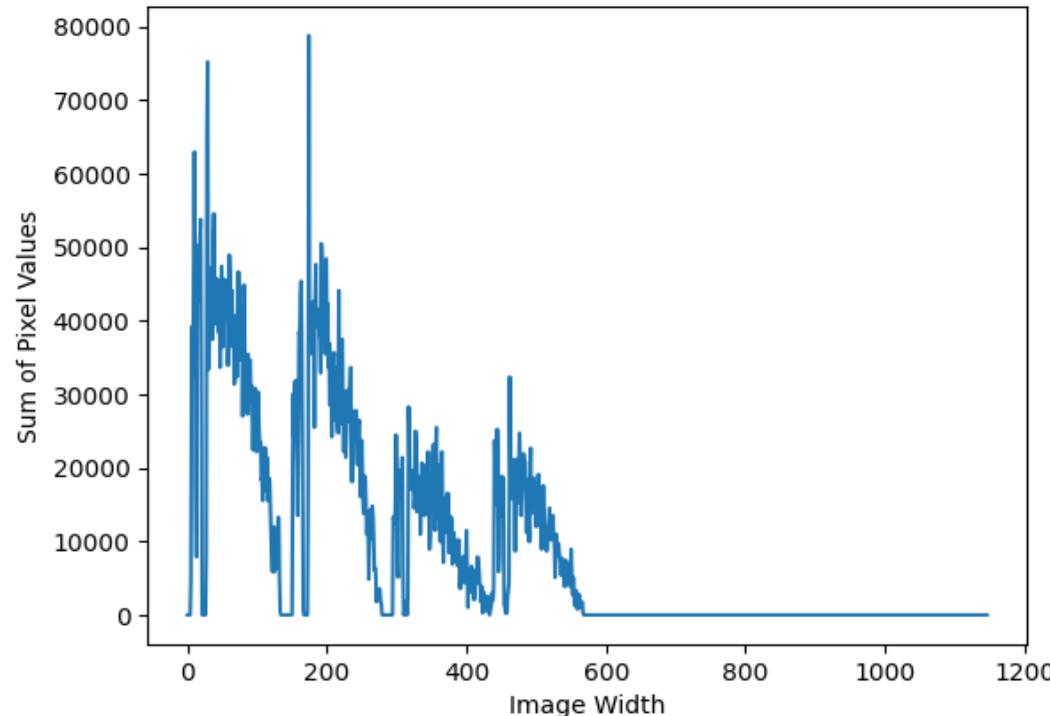


Separated Columns

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	65 El —, Texas
chipmunk	66 Point of development
16 Radius neighbor	67 Easy pitch
17 Motion picture	
18 San Juan is its capital (2 wds.)	
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17 Motion picture	57 Kickoff stands
18 San Juan is its capital (2 wds.)	59 Recipe amt.
20 Of durable wood	60 Menlo Park initis.



Vertical Projection Profile



Methodology - [6]

(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

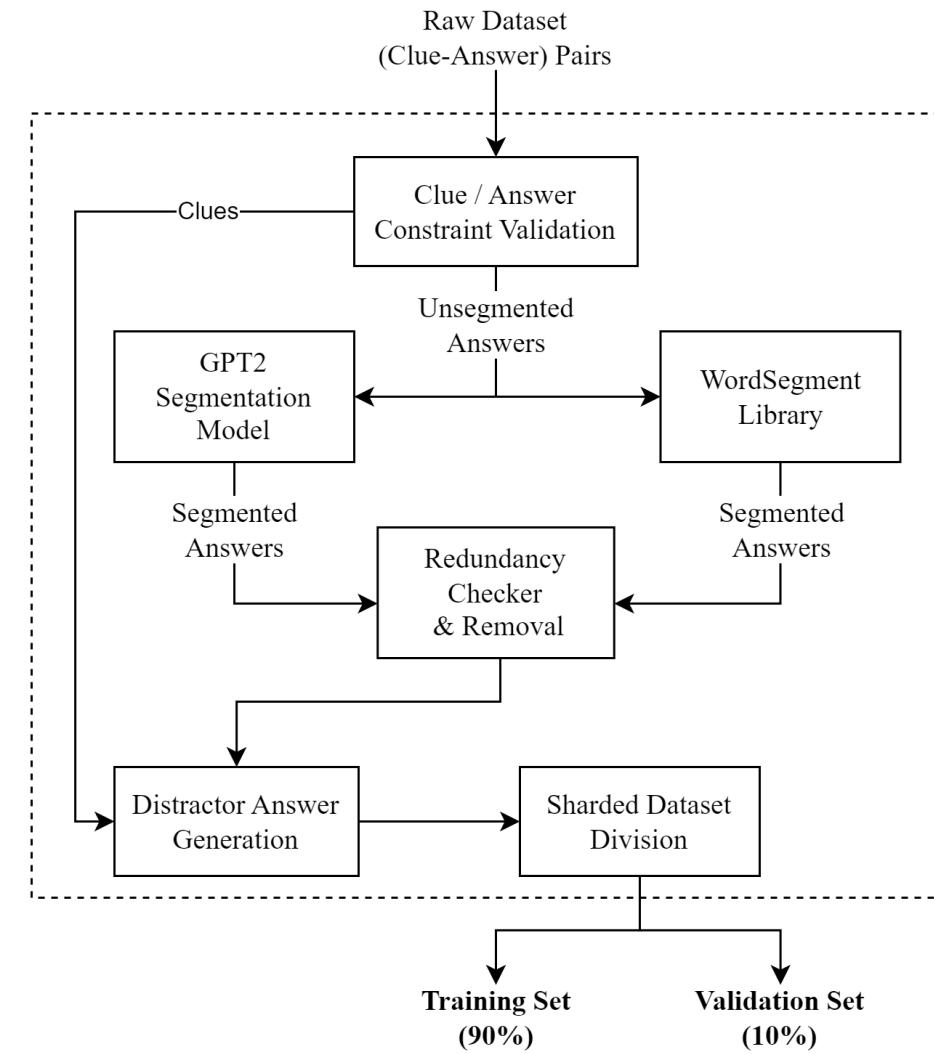
Down

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

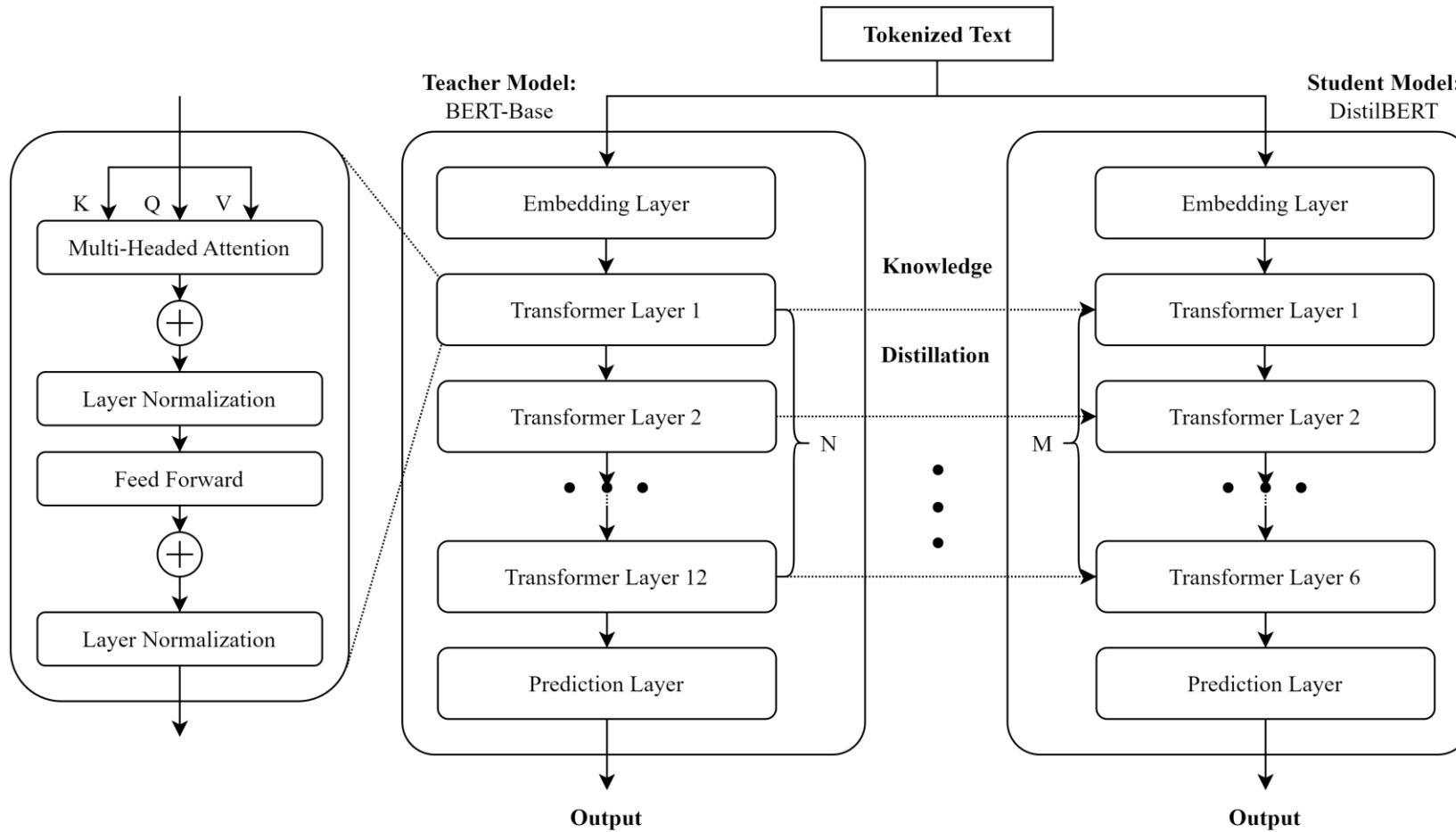
Extracted Clues

Methodology – [7] (Dataset Compilation, Extension and Preprocessing)

- Dataset compilation from 26 news outlets
- Dataset extension using BCS and Chinese dataset
- 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 – [8] (Architecture of DistilBERT Model)

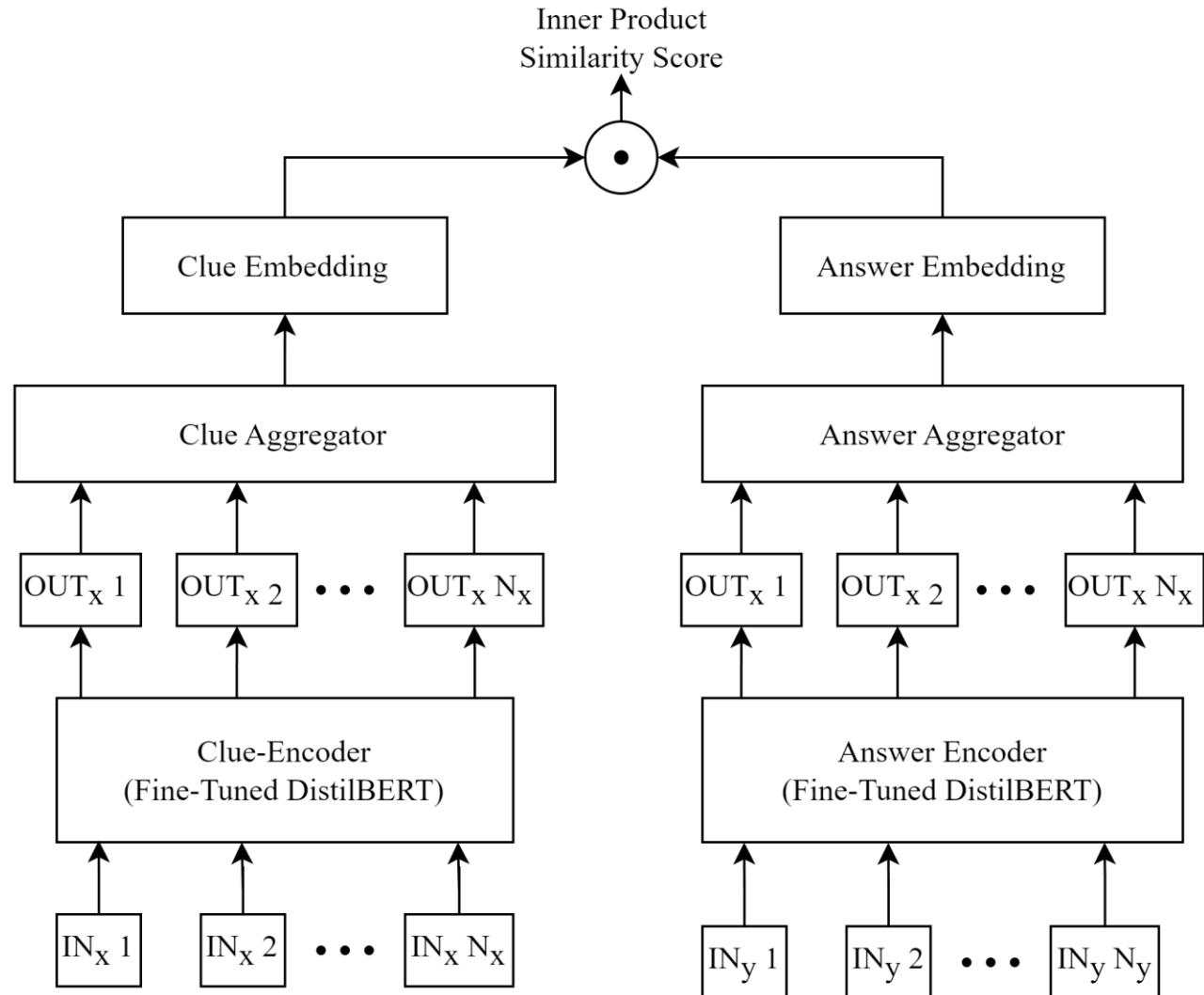


DistilBERT Model Features

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

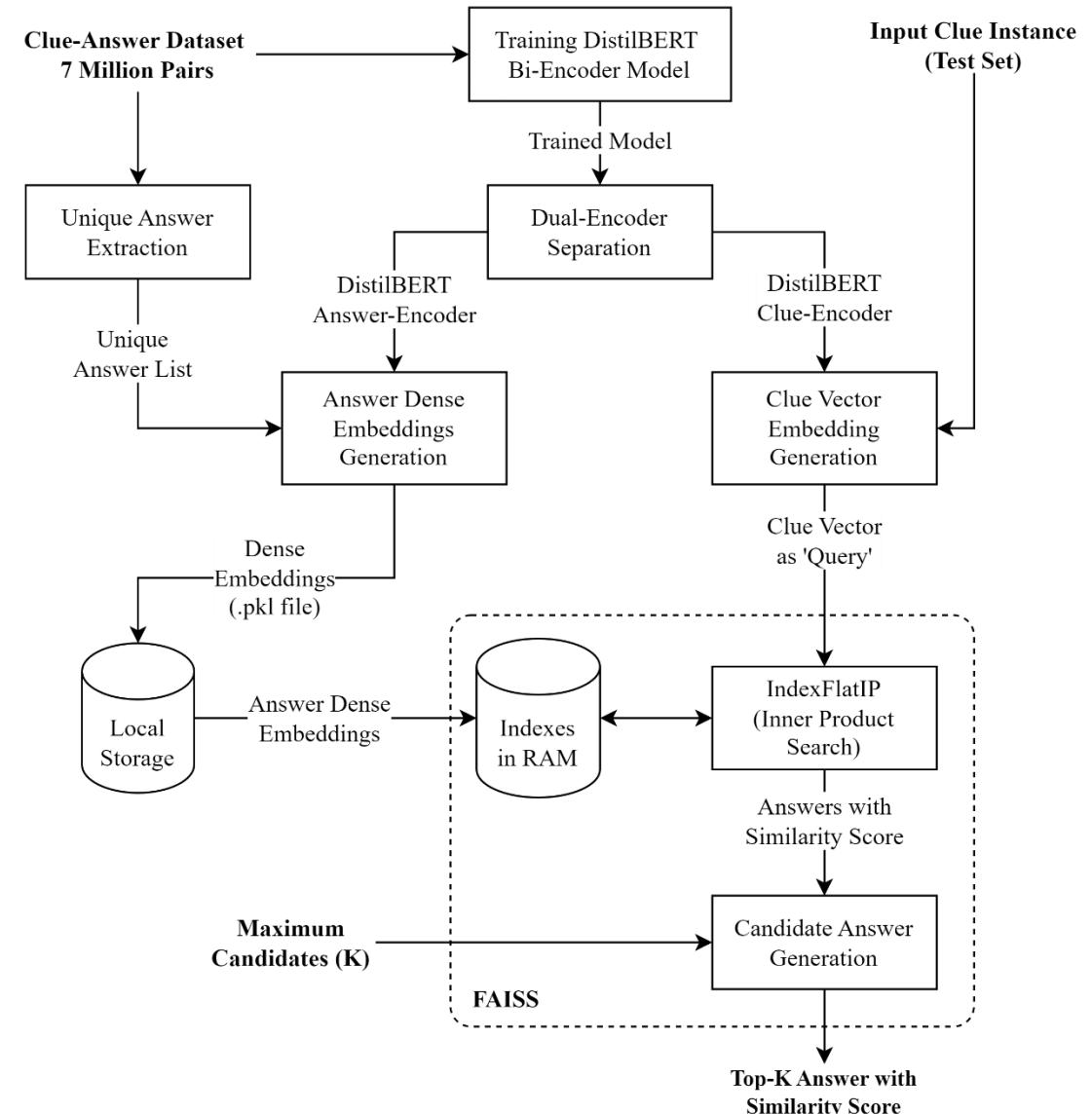
Methodology – [9] (Bi-Encoder Architecture)

- **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



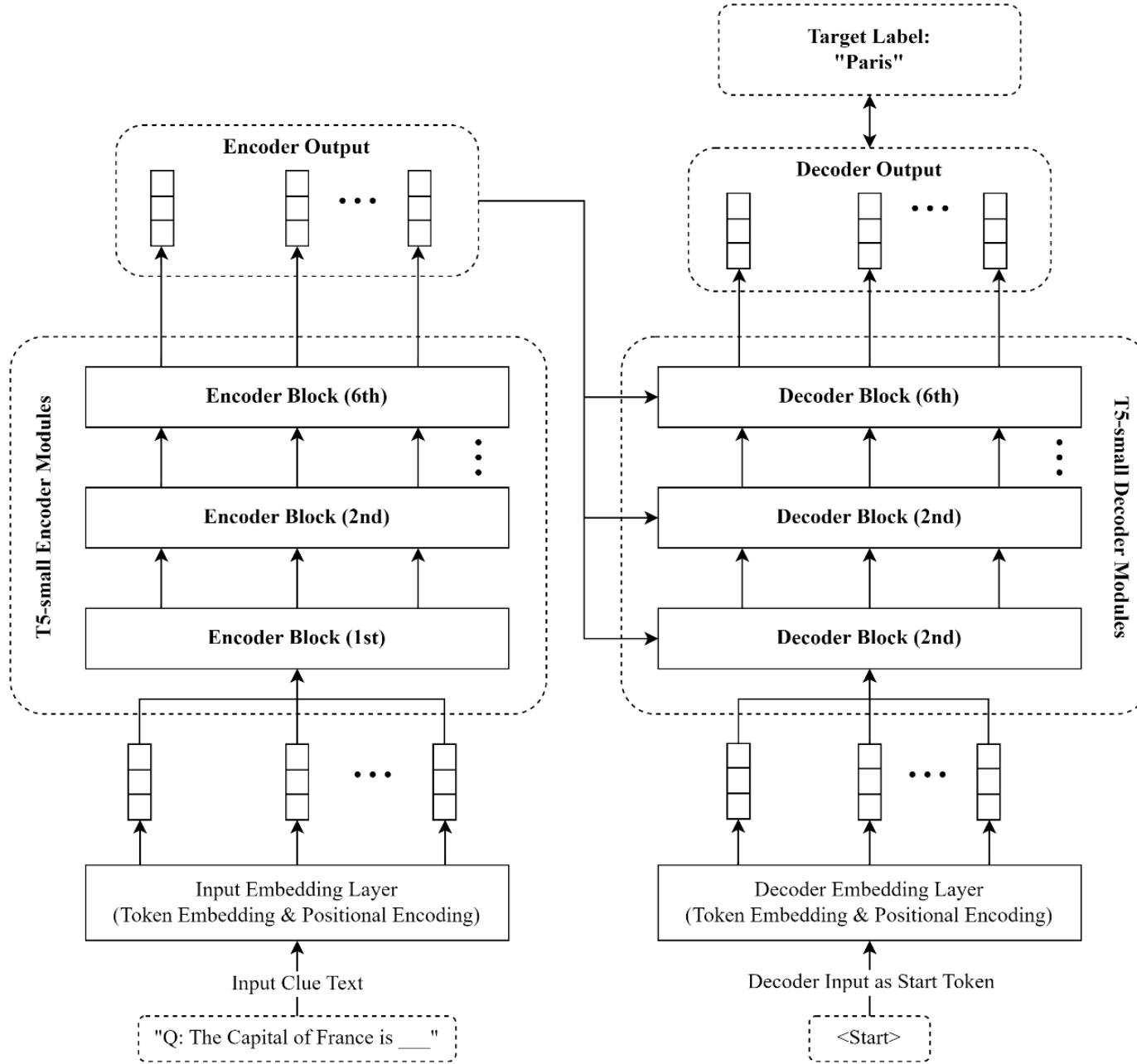
Methodology – [10] (Dense Answer Retrieval System)

- **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 – [11] (Architecture of T5-small Model)

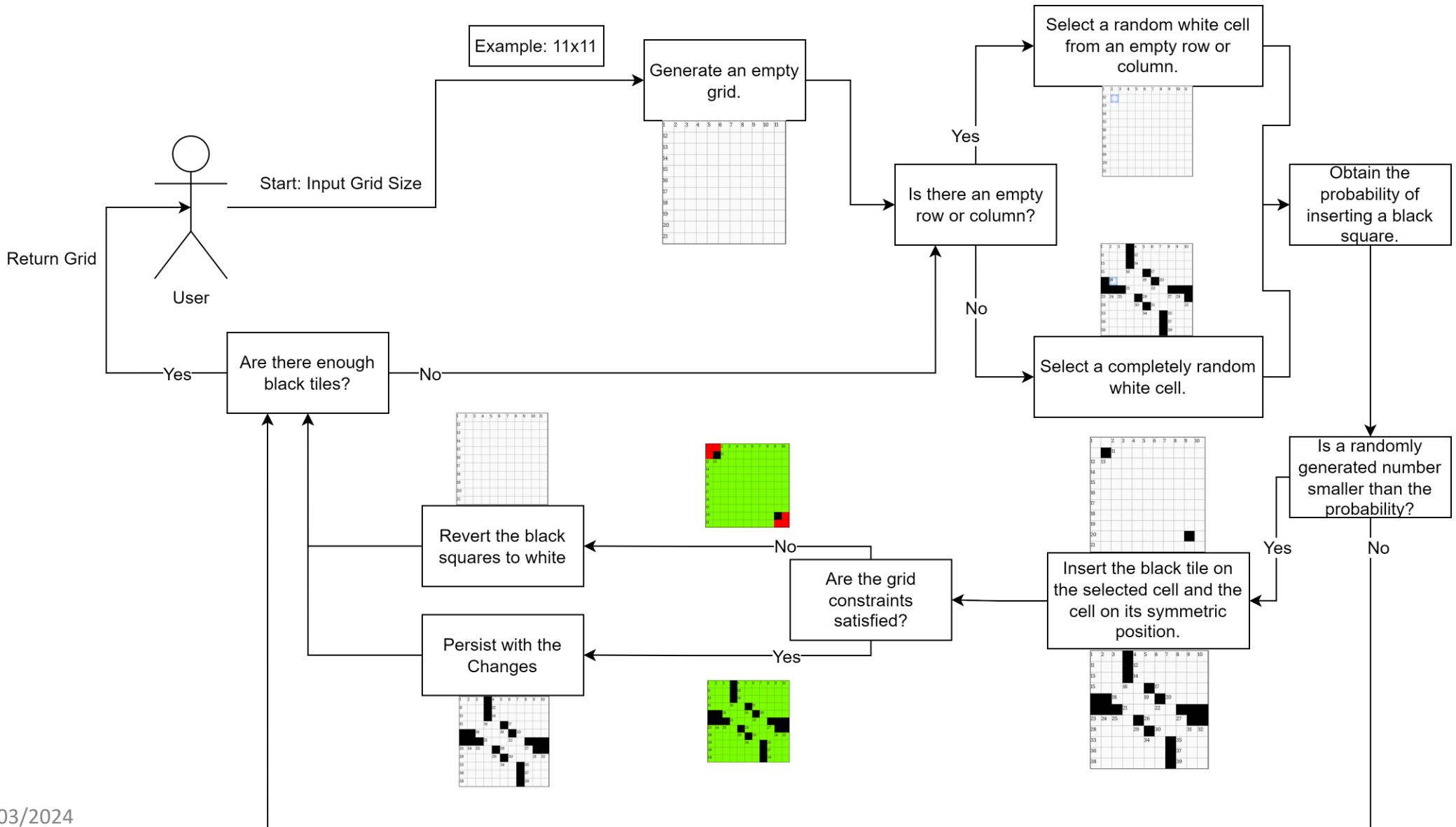
07/03/2024



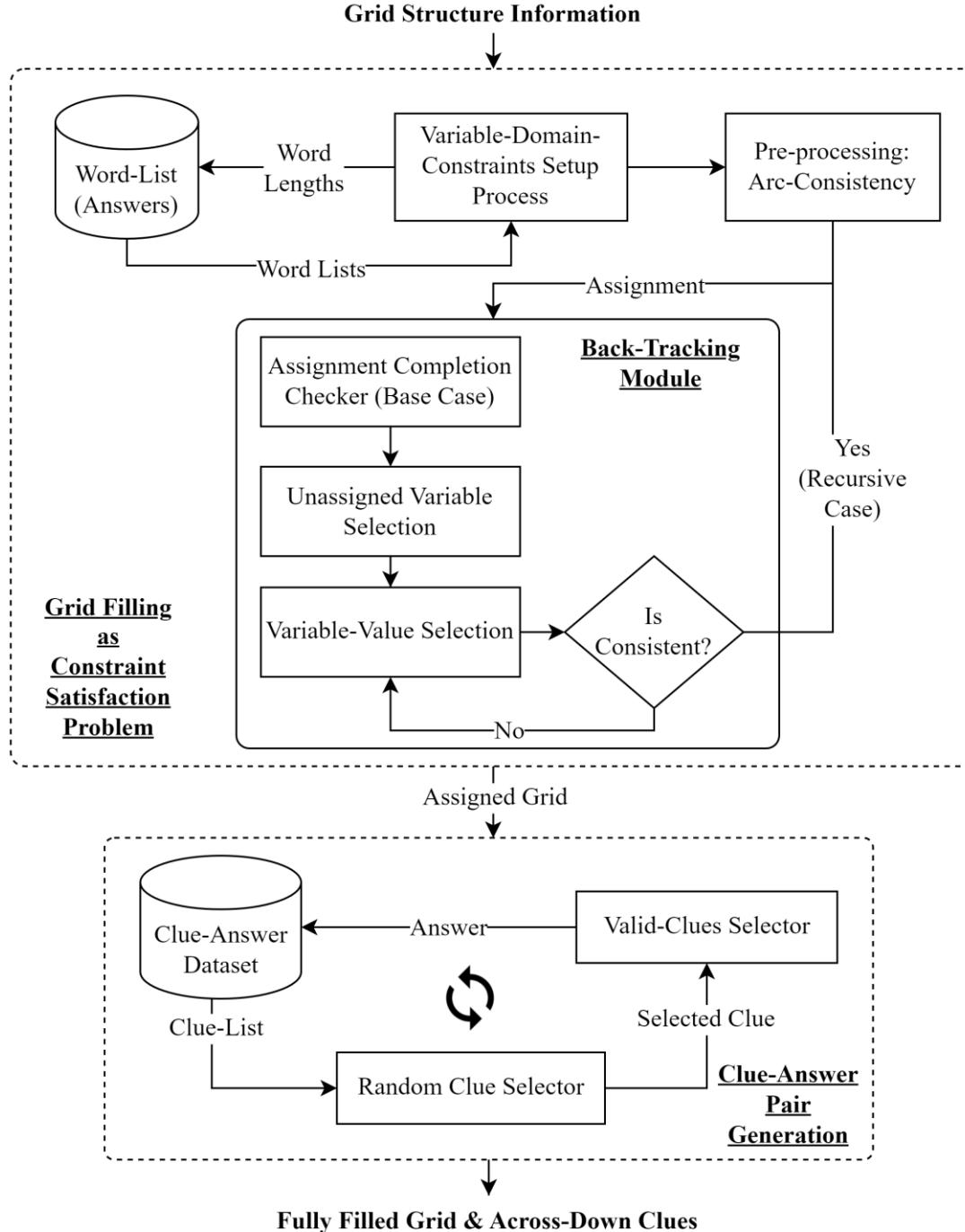
T5-Small Model Features

- Comprises a standard Transformer architecture with six encoder and six decoder stacks
- Utilizes a unified 'Text-to-Text' framework, facilitating easy training on custom tasks through instruct fine-tuning
- T5-small Parameter Count: 60.5 M

Methodology – [12] (Crossword Grid Generation)

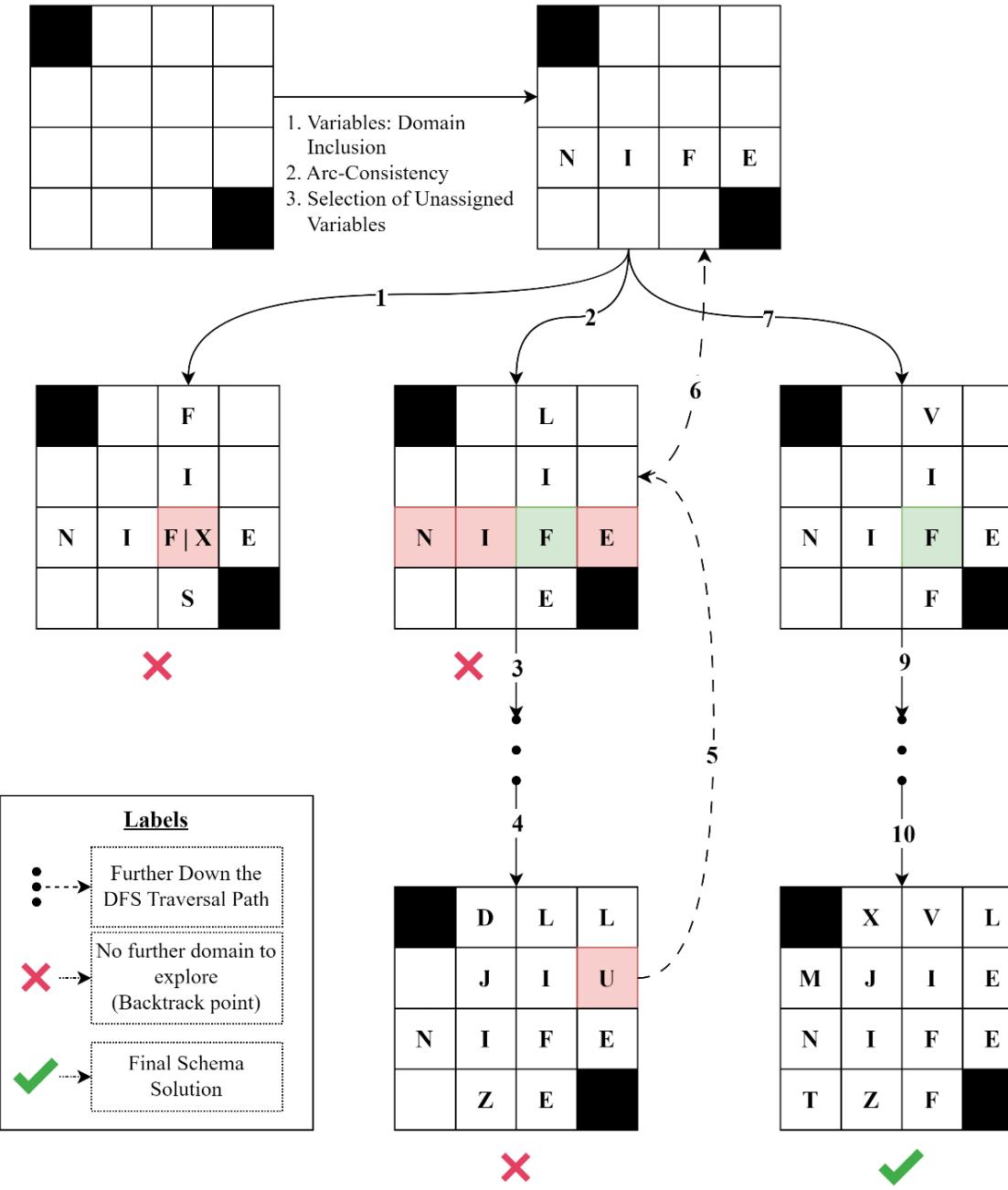


Methodology – [13] (Crossword Grid Filling as CSP & Clue-Answer Pair Generation)



- Crossword grid filling as Constraint Satisfaction Problem (CSP)
- Variables (Slots), Domains (Answers satisfying unary constraint), Constraints (American-Style Crossword Rules)
- CSP solved using Improved Back-tracking with Arc-Consistency and Forward Checking
- Smart selection of unassigned variables (Prominent problem faced in Crossword)
- Clue-Answer pair generated using the Clue-Answer Dataset

Methodology – [14] (Crossword Filling – Back-Tracking Demonstration)



- Arc-consistency reduces domain sizes during preprocessing.
- Backtracking begins with an unassigned variable, progressing with Depth-First Search.
- AC-3 internally prunes domains, facilitating backtracking when necessary.
- Iterative process continues until the time limit for schema completion is reached.

Methodology – [15] (Comparison Setup)

Comparison Setup with Dr. Fill & Berkeley Crossword Solver

- Trained DistilBERT-based Bi-Encoder on Crossword Data (1951 – 2020) made available by BCS Team via HuggingFace
- Testing dataset from 2021, averaged 120 crosswords sourced from The Atlantic, LA Times, New York Times, Newsday, and The New Yorker.

LLM Prompting for Crossword Solving

Provided below is essential information for a Crossword. Solve and give the output in {Clue – Answer} format.

Grid Size : [4X4]

Grid Structure: [[‘B’, ‘W’, ‘W’, ‘W’], [‘W’, ‘W’, ‘W’, ‘W’], [‘W’, ‘W’, ‘W’, ‘W’], [‘W’, ‘W’, ‘W’, ‘B’]]

Grid Numbering: [[0, 1, 2, 3], [4, 0, 0, 0], [5, 0, 0, 0], [6, 0, 0, 0]]

Clues:

Across: [“Sailor”, “Typography Symbol”, “Gave the nod”, “Hosp. Vehicle”]

Down: [“Up in the air, briefly”, “Liquid vessels”, “Charging medium, sometimes”]

Methodology – [16] (Instrumentation)

Hardware Resources

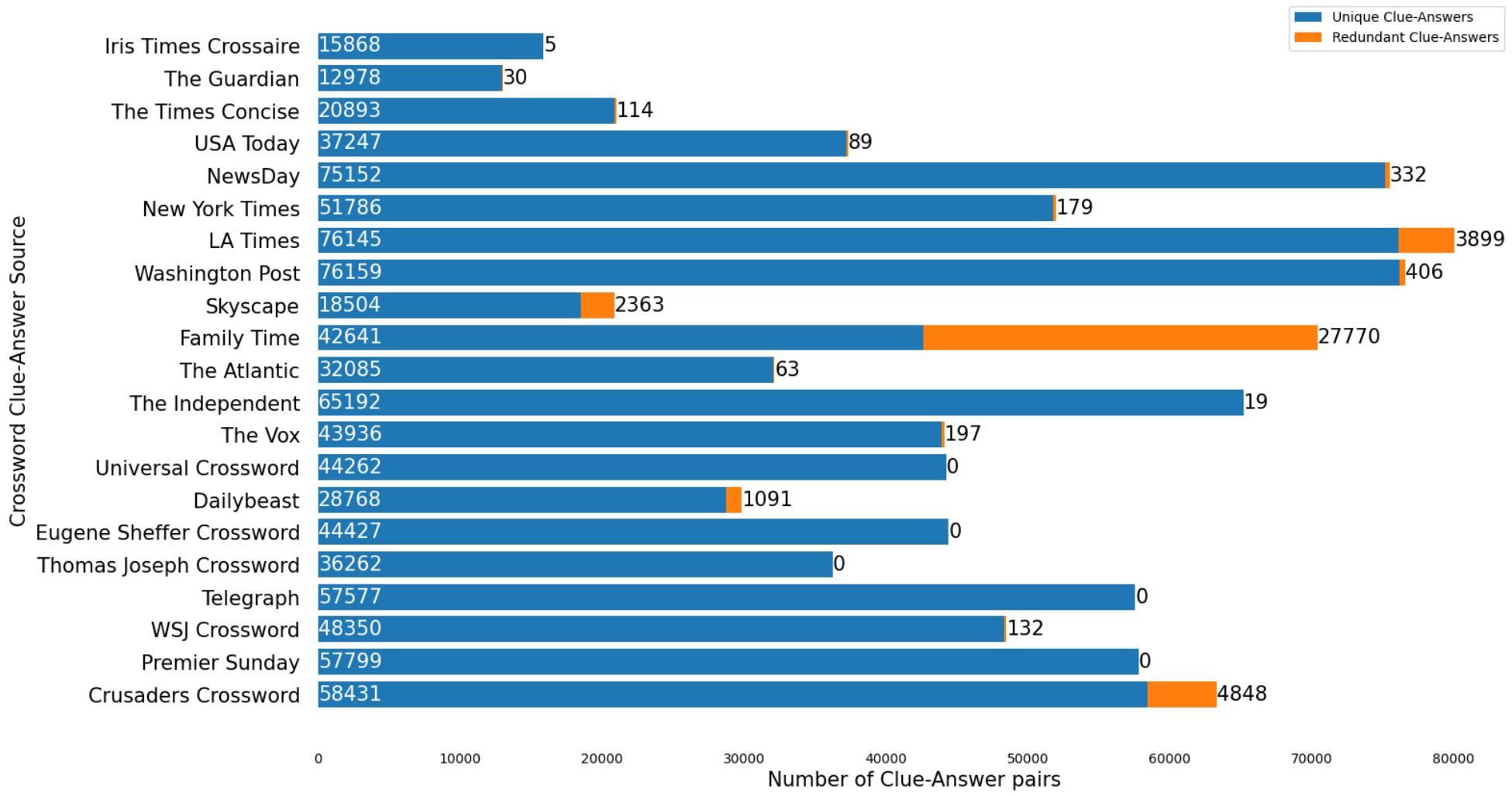
Parameter	Google Colab	Kaggle Kernel
GPU Name	NVIDIA K80 / T4	NVIDIA Tesla P100
GPU Architecture	NVIDIA Turing	NVIDIA Pascal
GPU Memory	12GB	16GB (16.28GB Usable) CoWoS HBM2 at 732 GB/s
NVIDIA CUDA Cores	4992	3584
RAM	~ 12 GB Available	~ 15.26 GB Available
Disk Storage	~ 108GB Available	~ 155 GB Available
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

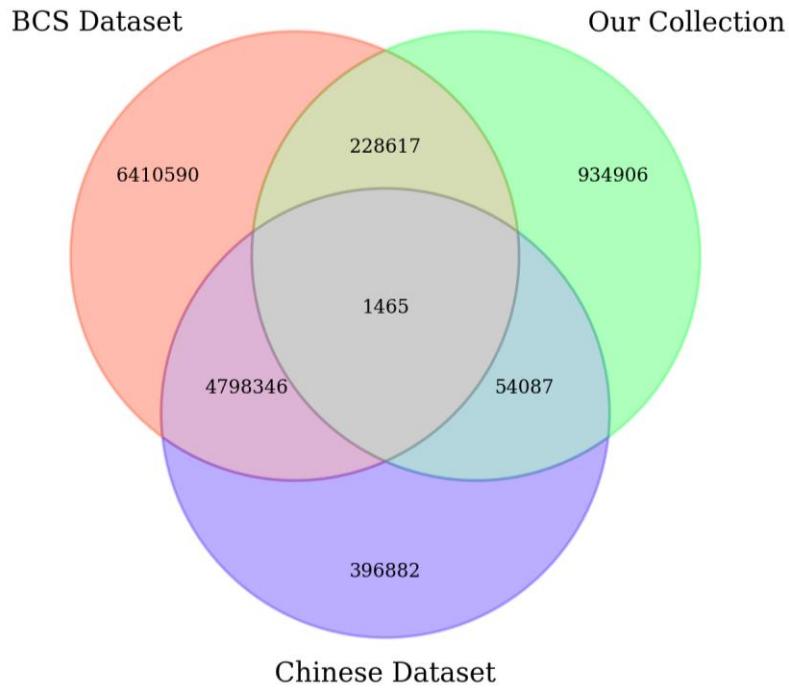
Library/Framework/Platform	Use
Tesseract	OCR for extracting clues.
Django	Backend development framework for the website.
PyTorch	Machine Learning Framework for training the models and inference.
OpenCV	Image processing for input refinement.
Hugging Face	Developing online APIs for the solvers and the generator.

Results and Analysis – [1]

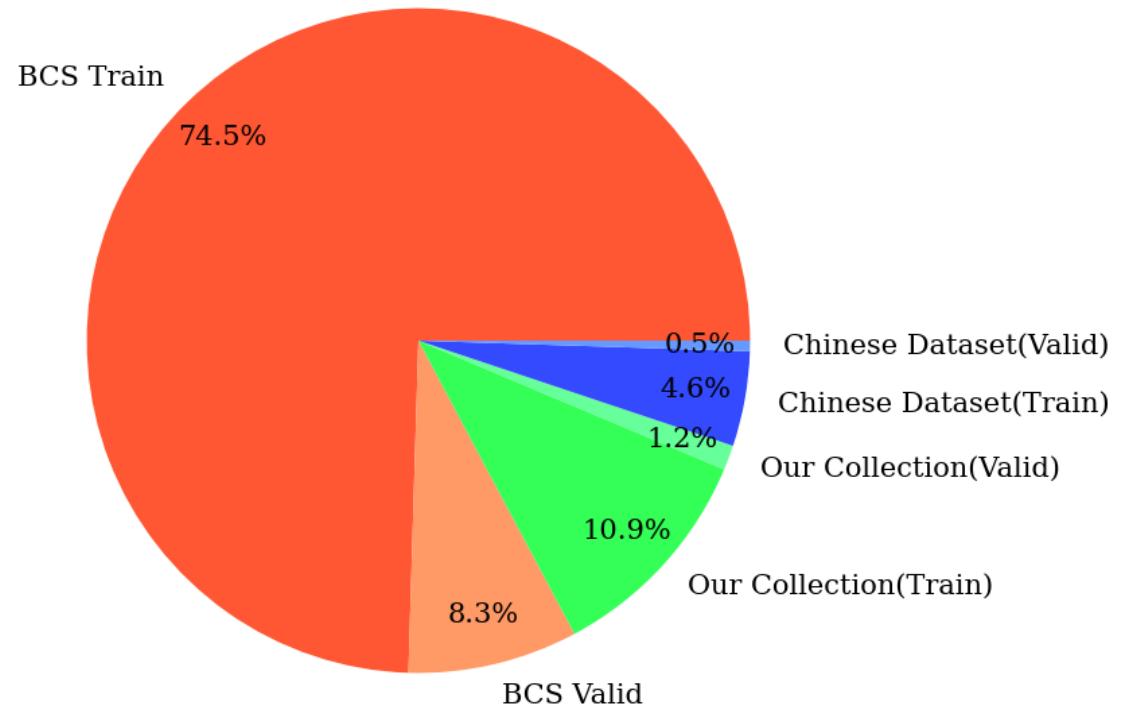
(Data Collection from 21 Online Sources)



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



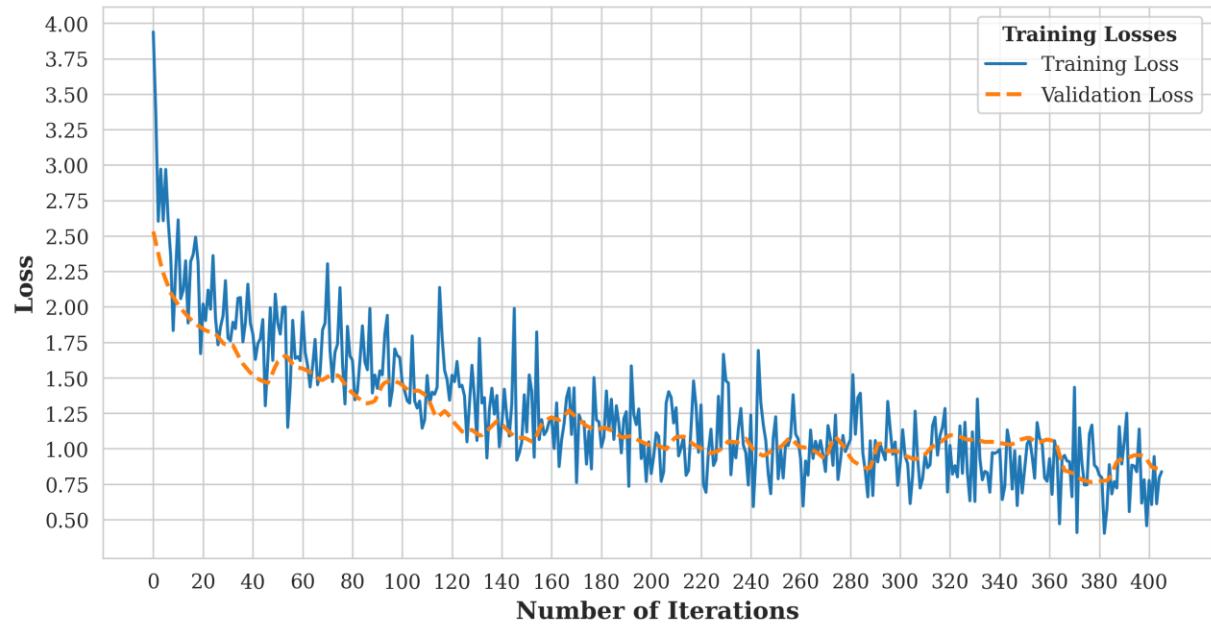
Data Overlap Among Various Sources



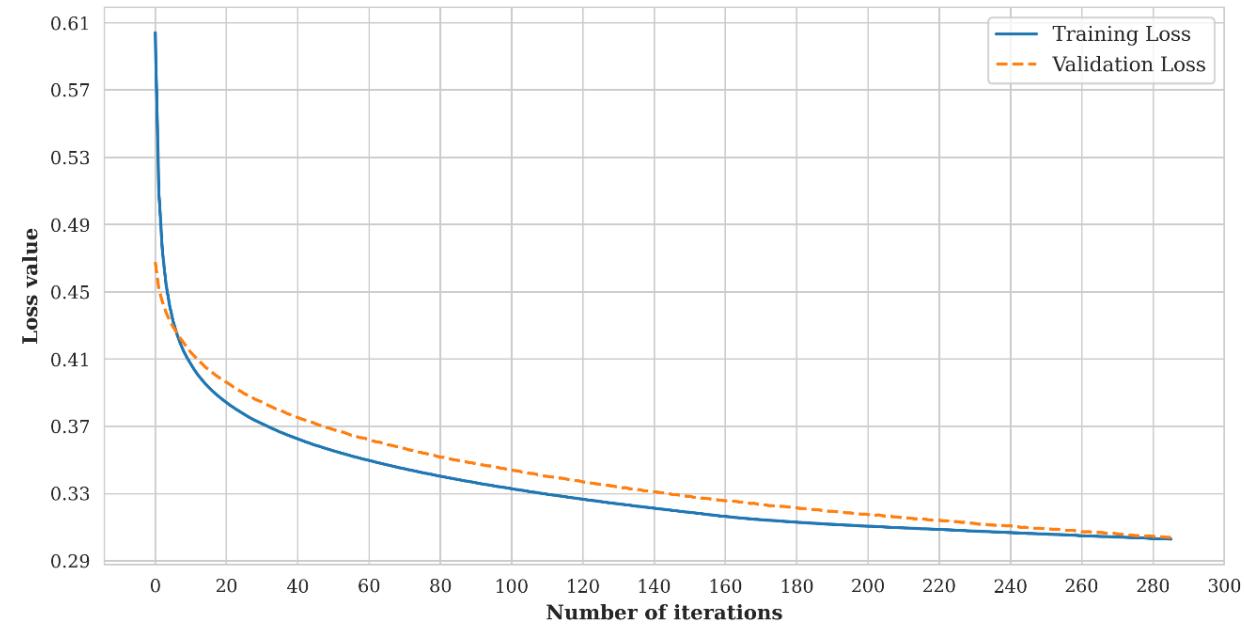
Overall Dataset Composition

Results and Analysis – [3]

(Training Vs. Validation Loss Curve)



DistilBERT Loss Curve



T5-small Loss Curve

Results and Analysis – [4] (Performance Metrics)

Top-K	Recall @ k	(NDCG @ k)
Top-1	13.64%	13.30%
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%

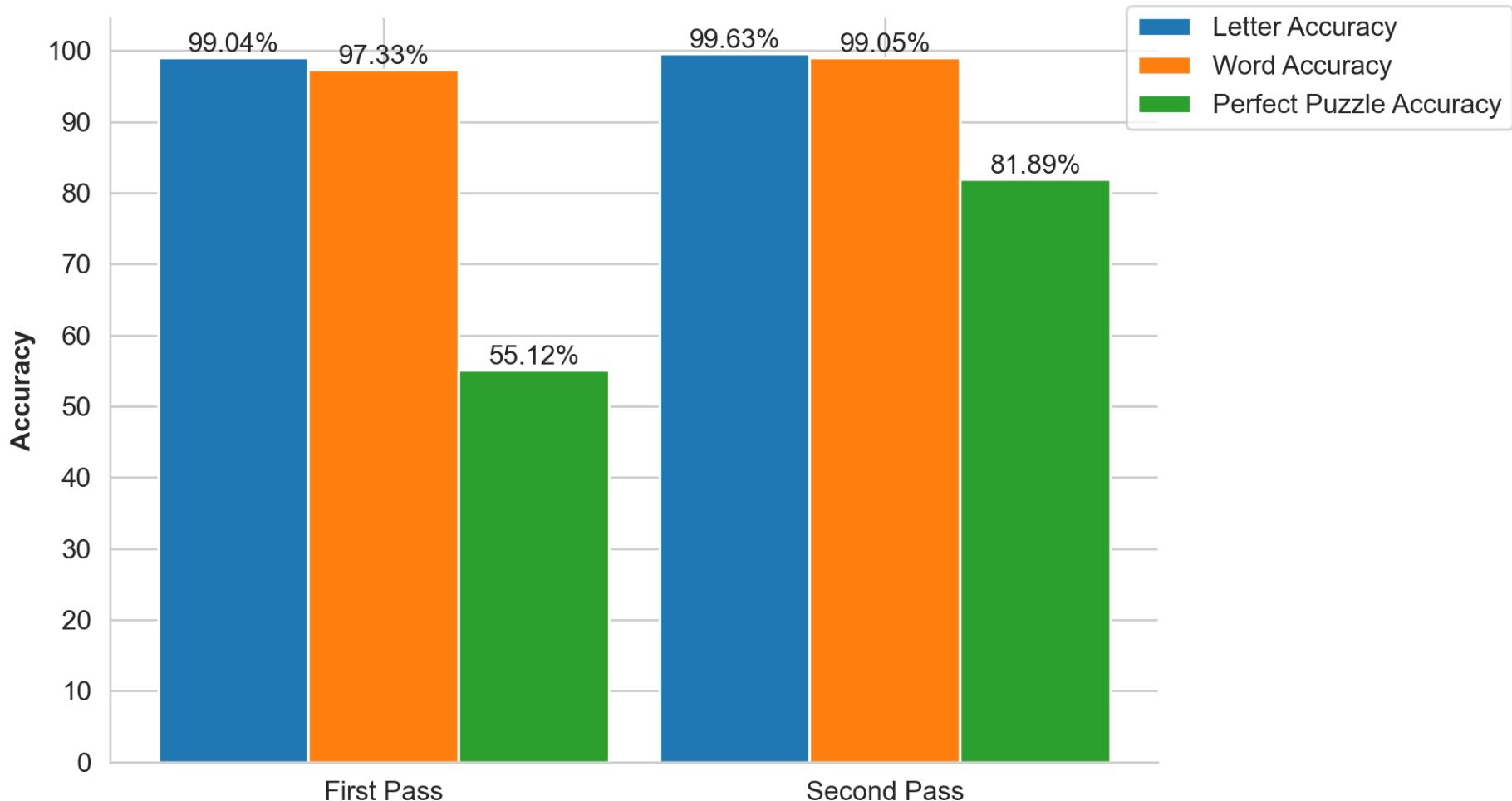
Metric Scores for
First Pass Model

- **Recall@K:** Measures the ability to rank the positive answers at the top K position
- **NDCG@K:** Measures relevance of correct answers in top-k candidates; higher values imply better ranking quality and result relevance.
- **MRR:** Measures the proximity of the positive answer's rank toward the top of the list;

Top-K	Recall@K
Top-1	77.4%
Top-2	77.4%
Top-5	77.8%
Top-10	79%
Top-20	80%
	T5-small
Average MRR Scores	78.0%

Metric Scores for
Second Pass Model

Results and Analysis – [5] (First-Pass vs Second-Pass Solver Metrics)



Results and Analysis – [6]

(Accurate Grid Extraction Instances)

CROSSWORD

ACROSS

- Techniques
- Opposite of most
- accomplish
- 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.
- “It’s freezing!”
- Flu bugs
- Introduce
- Fly by
- Deer mothers
- Sense of hearing
- Disembodies
- Car tag
- Pakistan’s language
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- “Exodus” hero
- Inspection
- Ill will

DOWN

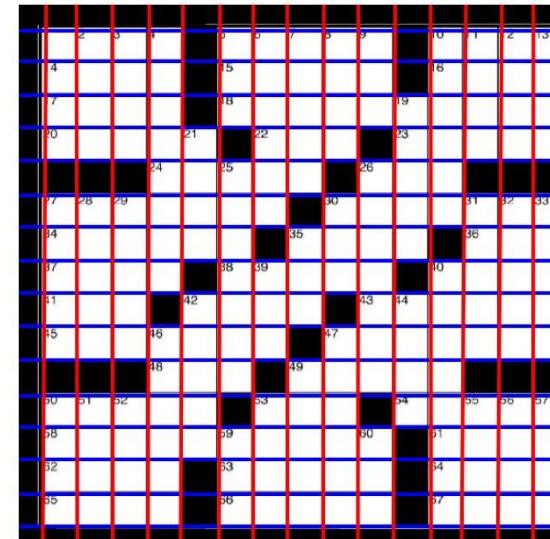
- Texas town
- Great Wall locale
- Jerk
- Increases in assembly line rates
- Once around a track
- Avoids capture
- Says decidedly
- Gentlemen
- Cable channel
- Commotions
- Landed
- Rainfall measure
- Town in New Mexico
- Ship’s record
- Lacking education
- Perk up
- This, in Spanish
- Become fond of (2 wds.)
- Cheap nightclubs
- Half diameters

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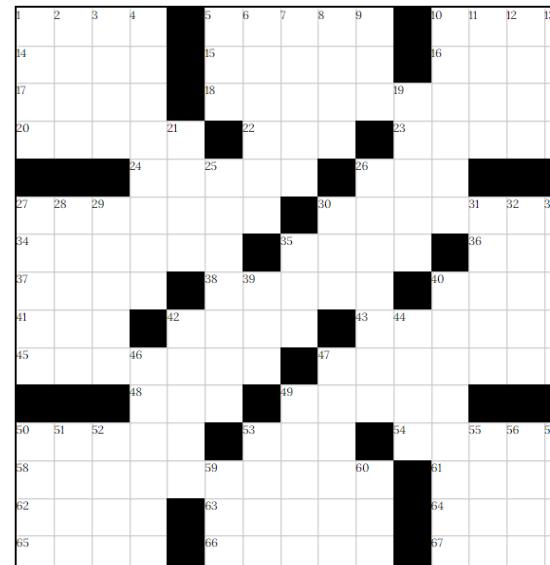
PREVIOUS PUZZLE SOLVED

C	H	E	R	S	C	R	A	P	O	M	E	N
14	62	Not much (2 wds.)	63	Barbara, Calif.	64	Publicity	65	El — Texas	66	Point of development	67	Easy pitch
17	68	Radius neighbor	69	San Juan is its capital (2 wds.)	70	Motion picture	71	“It’s freezing!”	72	Deer mothers	73	“Exodus” hero
20	74	Opposite of most	75	— accomplish	76	Without delay	77	Flu bugs	78	Sense of hearing	79	Inspection
24	80	Animated chipmunk	81	Barbara, Calif.	82	Publicity	83	Kiddie ride	84	“Exodus” hero	85	Opposite of most
25	86	Radius neighbor	87	San Juan is its capital (2 wds.)	88	Motion picture	89	Deer mothers	90	“It’s freezing!”	91	— accomplish
26	92	Opposite of most	93	Barbara, Calif.	94	Publicity	95	Sense of hearing	96	Inspection	97	Without delay
30	98	Radius neighbor	99	San Juan is its capital (2 wds.)	100	Motion picture	101	Deer mothers	102	“It’s freezing!”	103	— accomplish
31	104	Opposite of most	105	Barbara, Calif.	106	Publicity	107	Sense of hearing	108	Inspection	109	Without delay
32	109	Radius neighbor	110	San Juan is its capital (2 wds.)	111	Motion picture	112	Deer mothers	113	“It’s freezing!”	114	— accomplish

Scanned Image



Approximated Grid Borders



Final Digitized Grid

Results and Analysis – [7]

(Accurate Clue Extraction Instances)

CROSSWORD

ACROSS

- Techniques
- Opposite of most
- accompli
- 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
- Disenclumbers
- 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
- 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
- Gentlemen
- Cable channel
- Commotions
- Landed
- Rainfall measure
- Town in New Mexico
- Folklore giants
- Promontory
- Salting away
- Puppy seller
- Edge
- Helen of Troy's story
- Cheap nightclubs
- Half diameters

PREVIOUS PUZZLE SOLVED

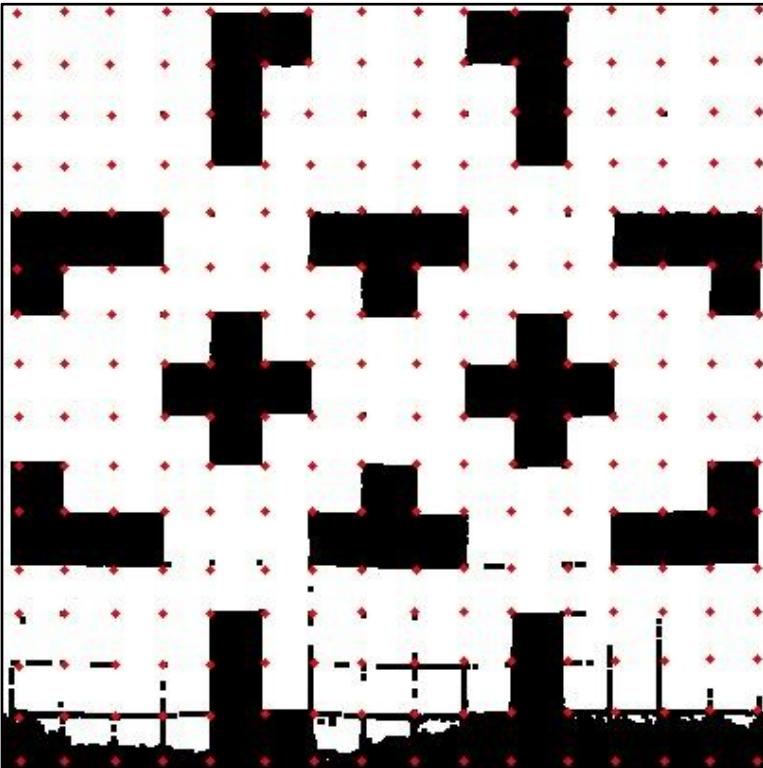
© 2023 UFS, Dist. by Andrews McMeel for UFS.

Original Image

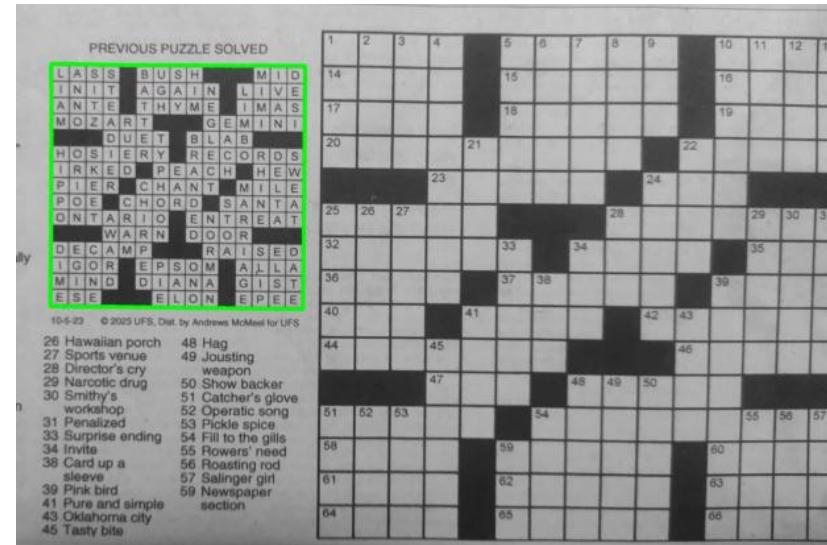
Across	Down
1 Techniques	1 Texas town
5 Opposite of most	2 Great Wall locale
10 — accompli	3 Jerk
14 Without delay	4 Increases in assembly line rates
15 Animated chipmunk	5 Once around a track
16 Radius neighbor	6 Avoids capture
17 Motion picture	7 Says decidedly
18 San Juan is its capital (2 wds.)	8 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

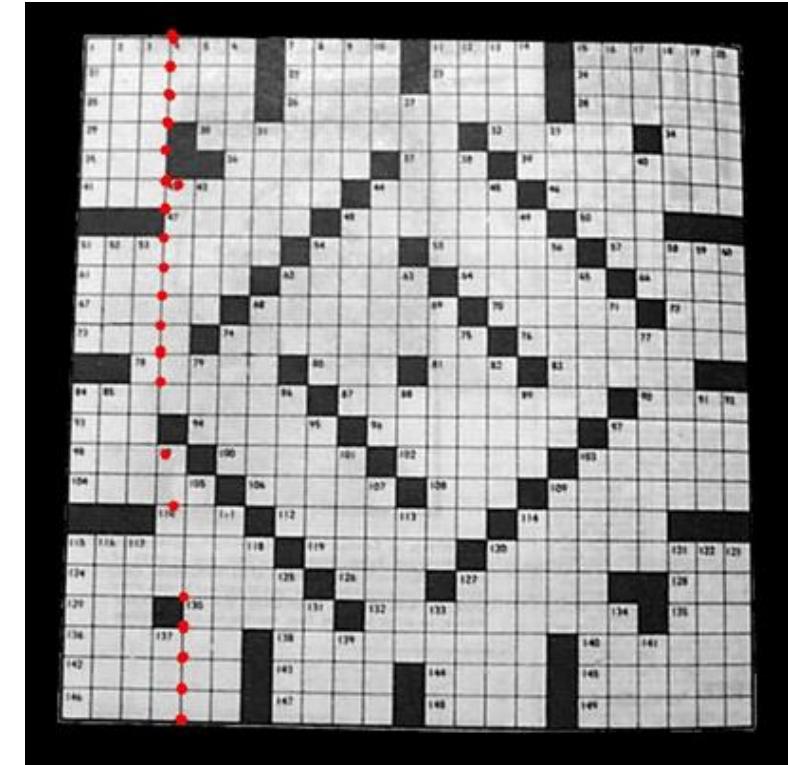
Results and Analysis – [8] (Errors in Grid Extraction)



Error In Binarization



Wrong Contour Selection

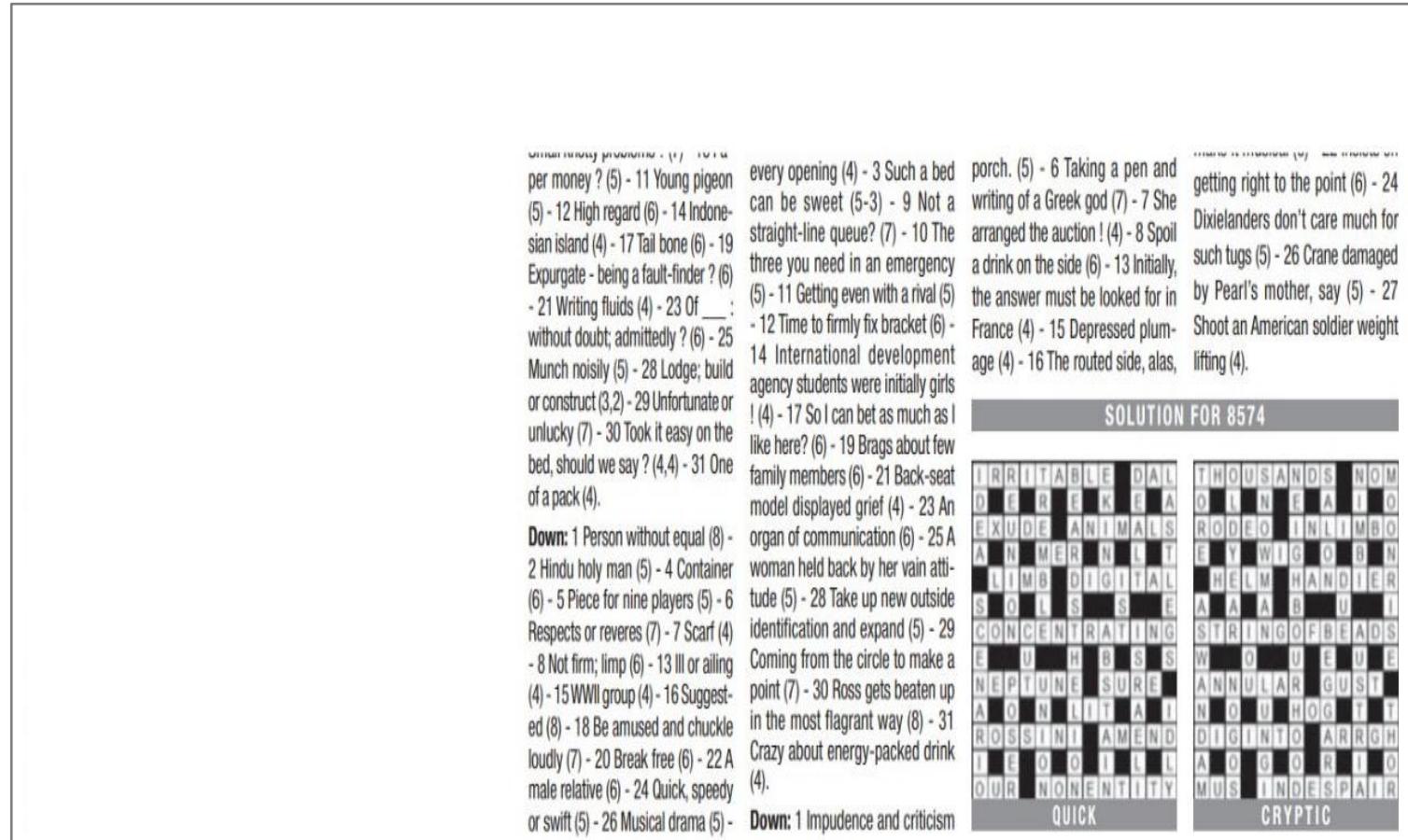


Incorrect Corner Grouping

Results and Analysis – [9] (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 – [10]

(Crossword Solver – First Pass & Second Pass)

NYT Crossword - 07/27/2023

Letter Accuracy: 97.84 % Word Accuracy: 92.31 %



First Pass Output

NYT Crossword - 07/27/2023

Letter Accuracy: 99.46 % Word Accuracy: 97.44 %



Second Pass Output

Results and Analysis – [11]

(Comparison with Previous Systems – Dr. Fill & BCS)

Dr. Fill System

- Developed by Matt Ginsberg; solves American-style crossword puzzles.

Berkeley Crossword Solver

- Proposed by Eric Wallace and Albert Xu from University of California Berkeley in 2021.

Source	Perfect Puzzle (%)			Word Acc. (%)			Letter Acc. (%)		
	Dr. Fill	BCS	Ours	Dr. Fill	BCS	Ours	Dr. Fill	BCS	Ours
The Atlantic	82.6	89.1	95.8	98.5	99.1	99.8	99.7	99.8	99.9
Newsday	86.2	94.2	88.5	98.6	99.6	99.5	99.1	99.8	99.9
The New Yorker	86.4	77.2	87.8	99.5	98.9	99.5	99.9	99.8	99.9
The LA Times	81.5	92.6	87.5	99.4	99.7	99.0	99.9	99.9	99.6
The New York Times	70.5	81.7	93.0	97.9	98.9	99.5	99.2	99.7	99.9

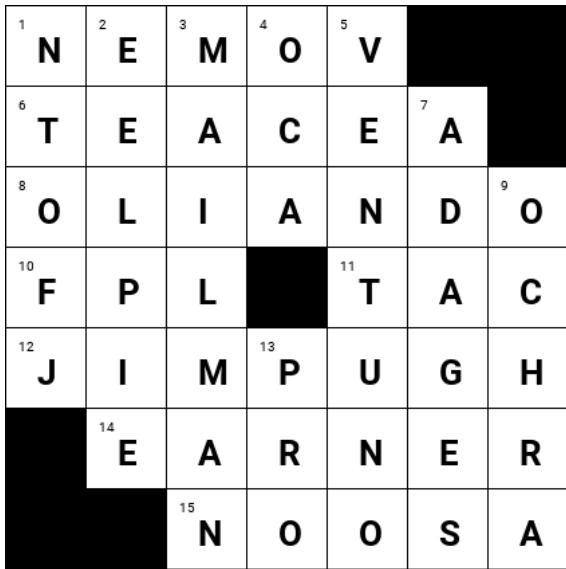
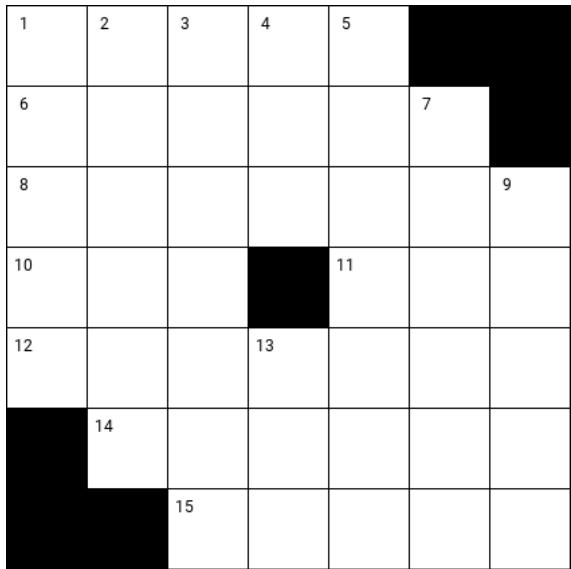
Results and Analysis – [12]

(LLM Solving Ability Assessment: ChatGPT & Co-Pilot)

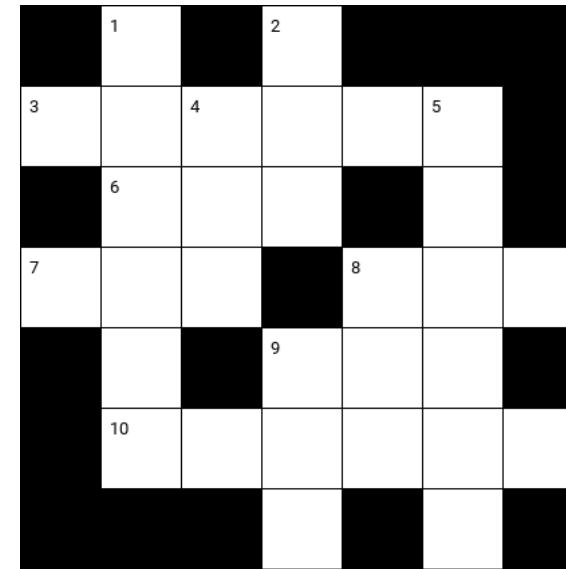
S.N.	Date	Grid Size	ChatGPT-Solved	Co-Pilot-Solved	Ours (Second Pass Result)
			Words Accu.	Words Accu.	Words Accu.
1	1/8/2024	15	72.73%	75.32%	100%
2	8/1/2023	15	60.26%	71.79%	100%
3	8/15/2023	15	67.61%	73.61%	97.30%
4	8/20/2023	21	43.38%	56.67%	100%
5	9/7/2023	15	51.35%	57.33%	100%
6	10/21/2023	15	32.81%	43.08%	100%
7	10/31/2023	15	75.34%	80.56%	100%
8	11/14/2023	15	67.57%	74.67%	100%
9	11/21/2023	15	67.11%	72.37%	100%
10	12/1/2023	15	35.94%	33.33%	100%
Average Accuracies			57.41%	63.87%	99.73%

Results and Analysis – [13]

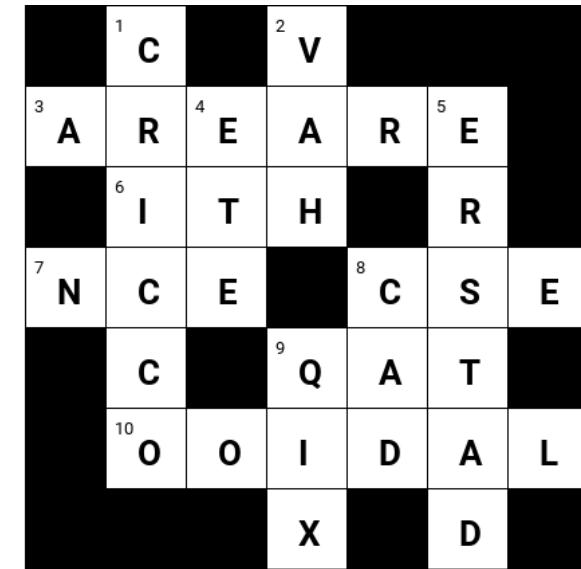
(Crossword Grid Generation – Small Sized)



7 x 7 – American-styled Crosswords

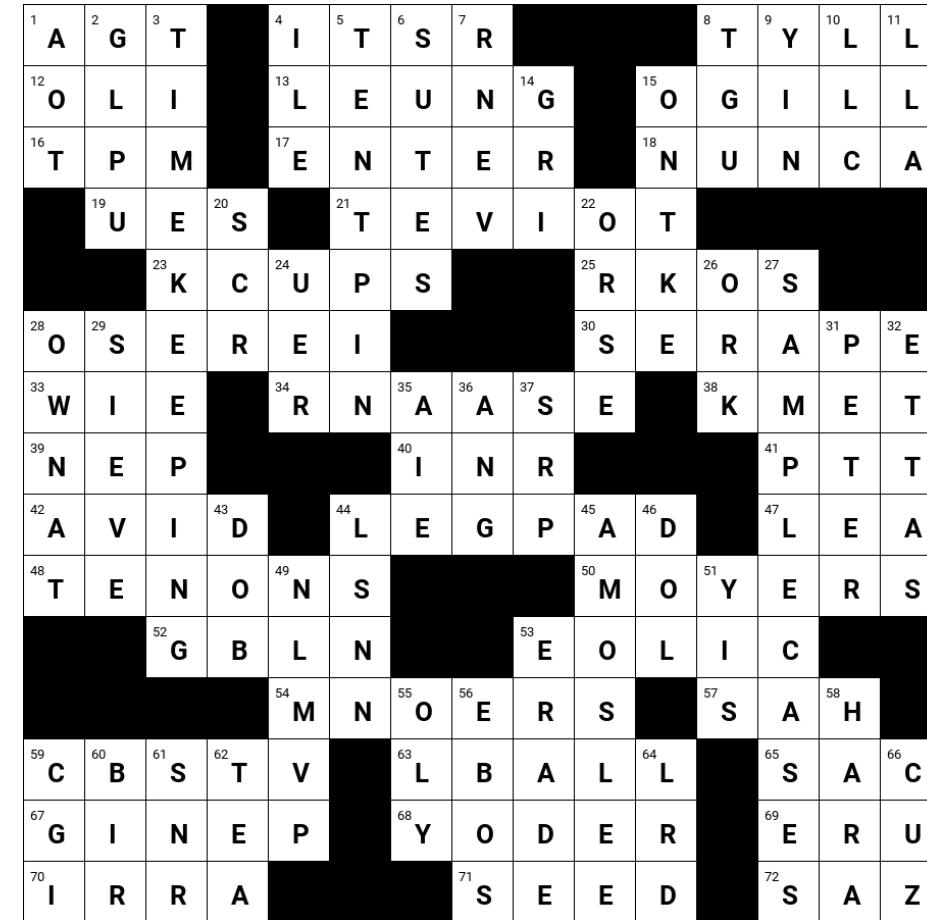
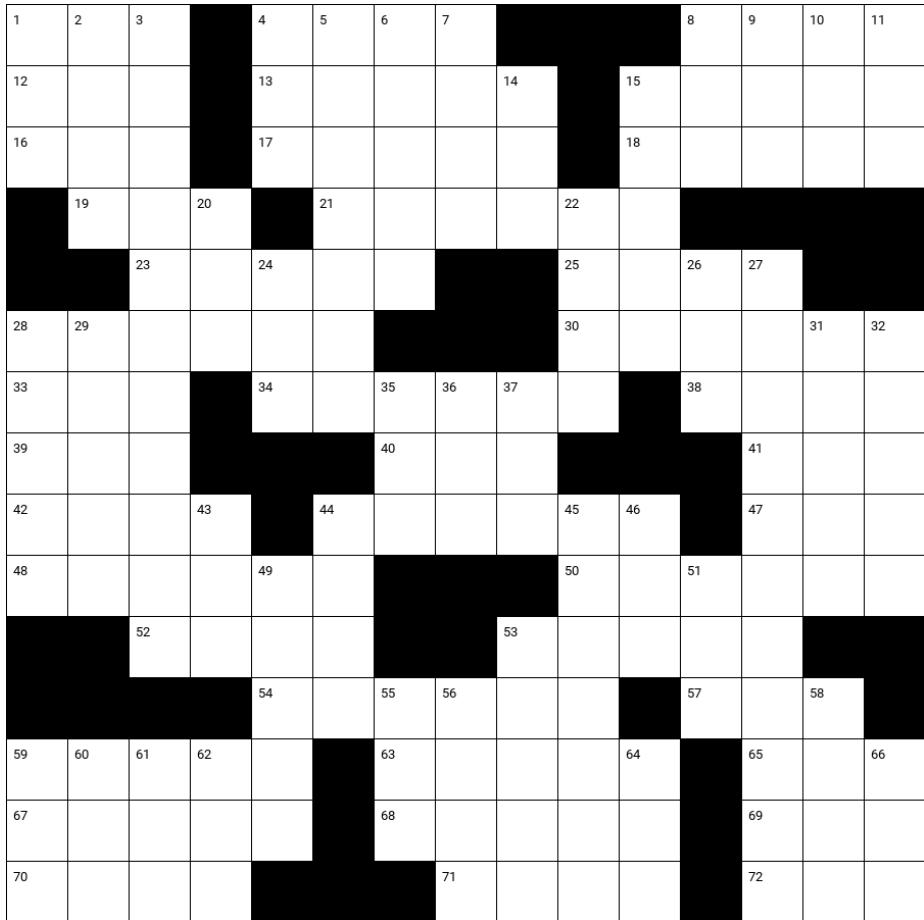


7 x 7 – British-styled Crosswords



Results and Analysis – [14]

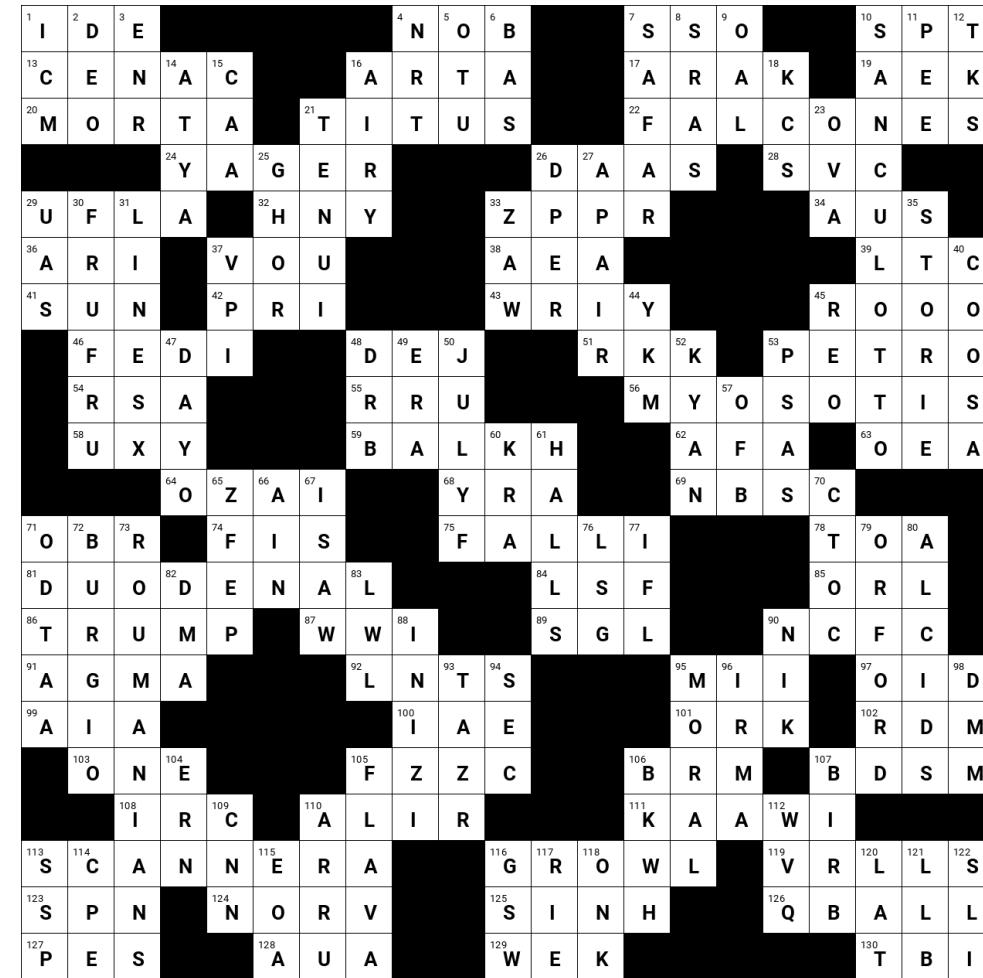
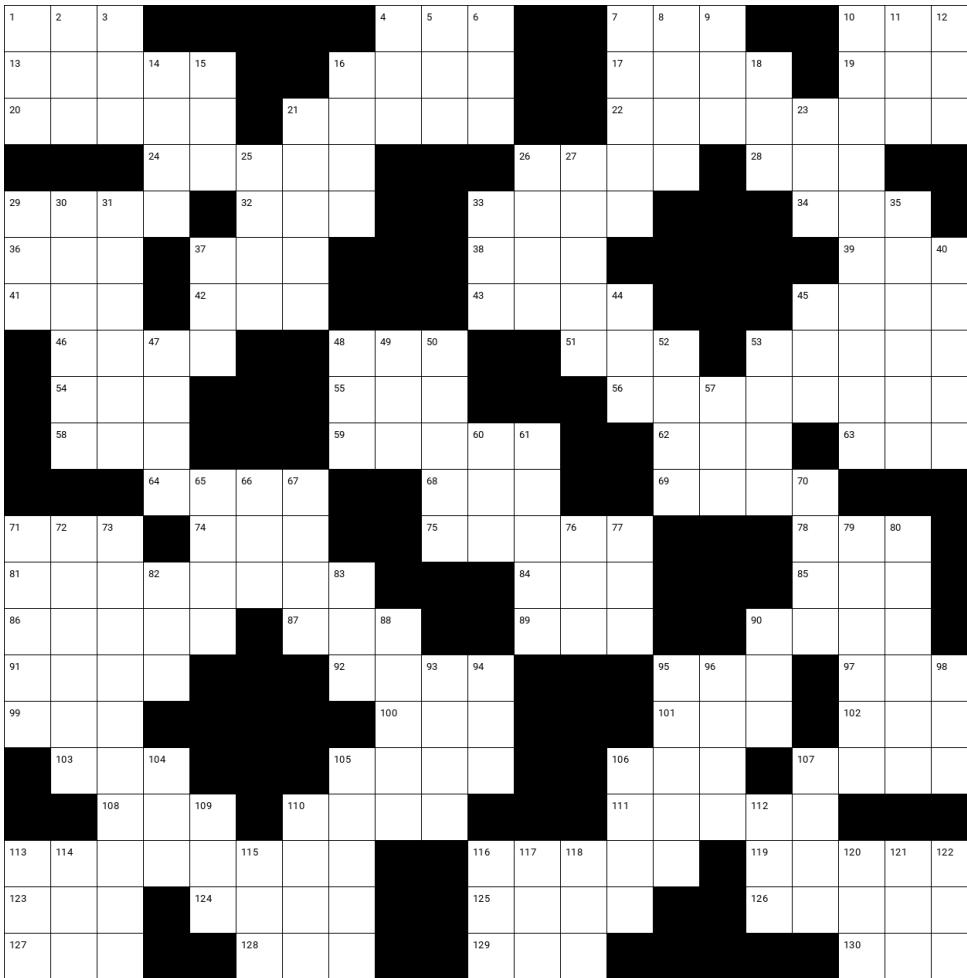
(Crossword Grid Generation – Medium Sized Grid)



15 x 15 – American-styled Crosswords

Results and Analysis – [15]

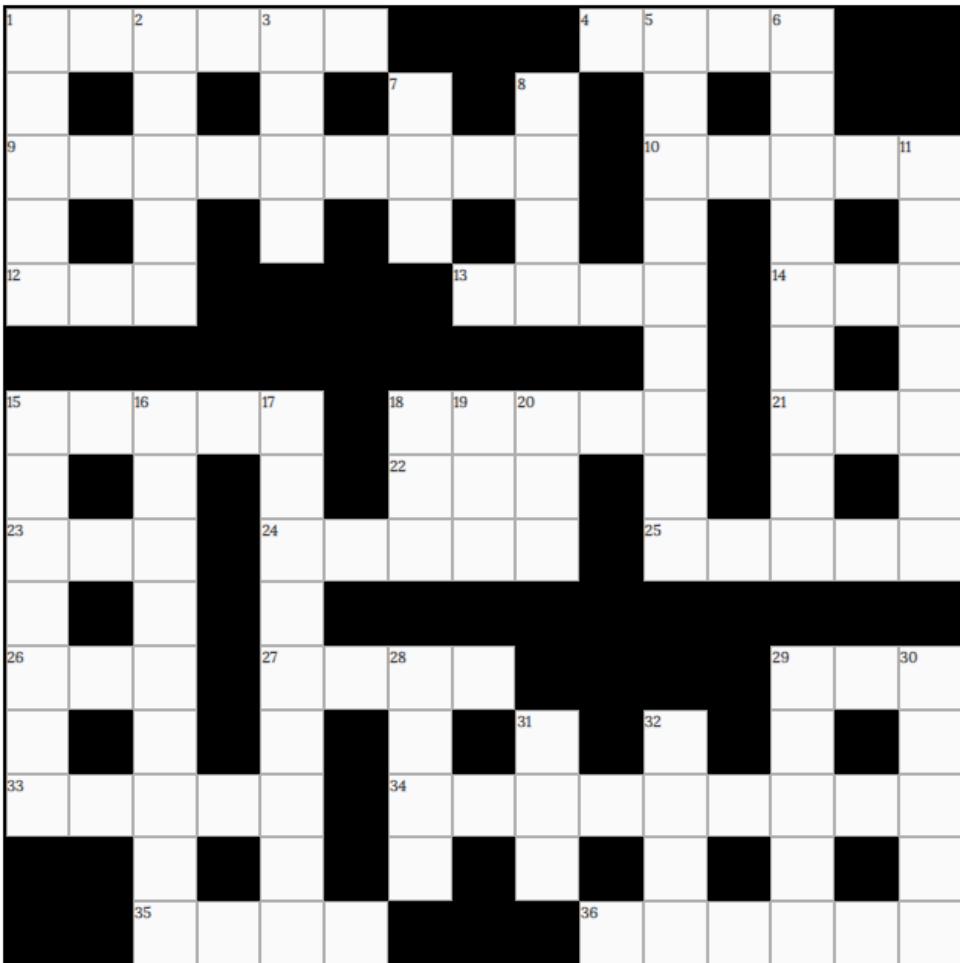
(Crossword Grid Generation – Large Sized Grid)



21 x 21 – American-styled Crosswords

Results and Analysis – [16]

(Crossword Grid Generation – Medium Sized Grid)

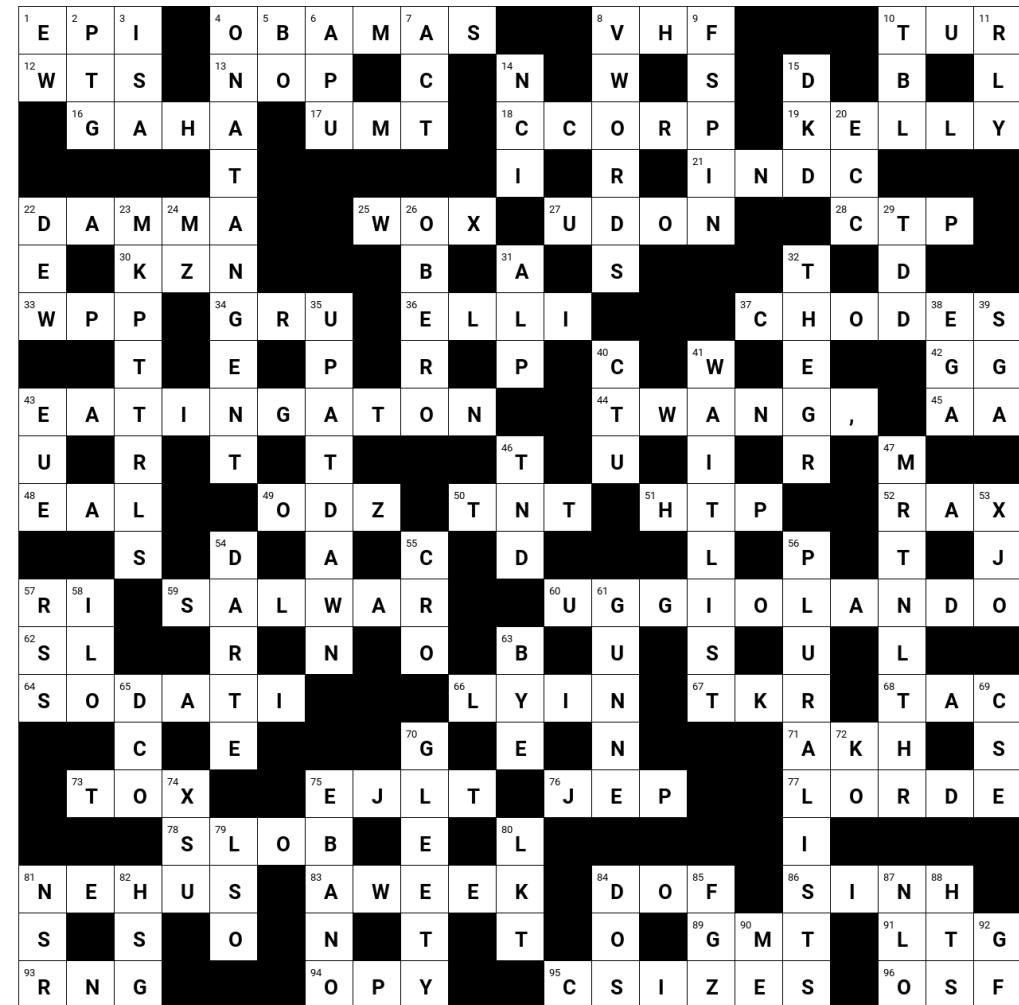
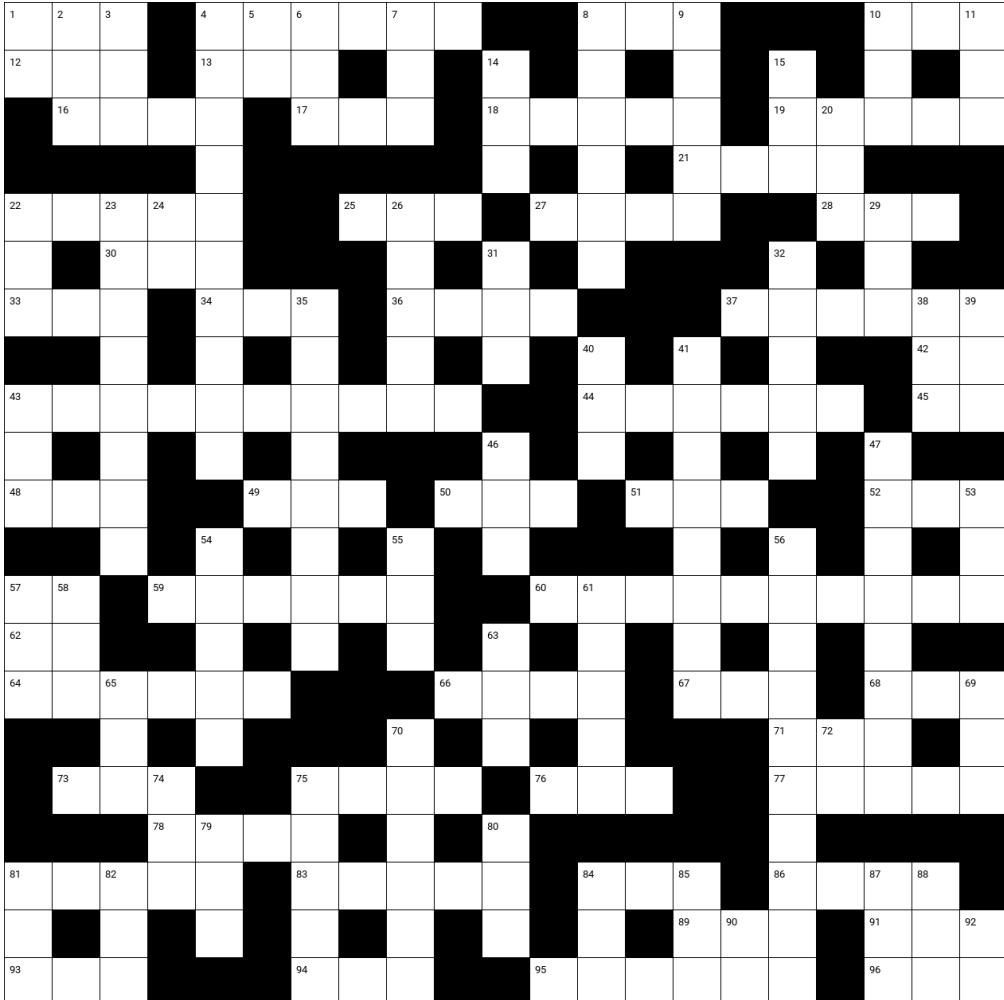


1	S	I	2	N	W	3	A	V			4	A	5	U	S	6	T	
9	O		I		R		B		I		N		O					
10	N	A	K	E	D	F	A	C	T		L	A	M	I	11	T		
11	N		L		A	R		M		A	B		O					
12	A	L	A				E	A	U	S	A	A	M	H	R	A		
13															21	O	N	T
14															Z	D	P	
15	A	G	16	A	D	17	A		18	F	19	I	20	D	A	I		
16	Z		17	D		18	S	D	19	R	N	L	O					
17	O	A	M		24	R	E	I	F	S	25	G	O	A	D	S		
18	V		I	M														
19	S	M	R		27	A	F	28	I	N	29	F	N	30	C			
20	E		A	Y		28	A		31	R	32	F	O	R				
21	A	B	B	A	J	34	S	M	A	M	M	A	R	S	I			
22	L		U		A	35	E	R	N	A	H	R	E	T				
23	35	E	R	N	A		P	I	L	L	S	,						
24																		
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36																		

15 x 15 – British-styled Crosswords

Results and Analysis – [17]

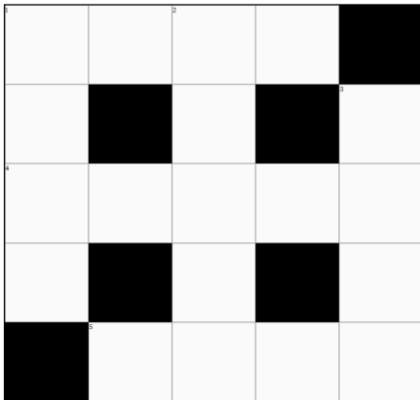
(Crossword Grid Generation – Large Sized Grid)



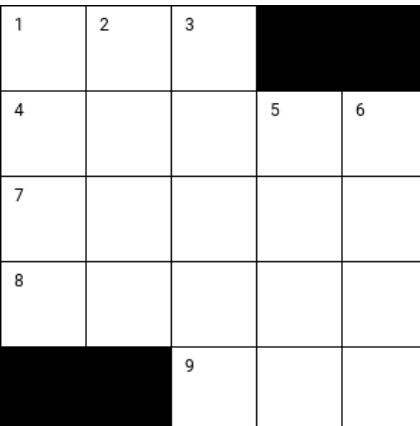
21 x 21 – British-styled Crosswords

Results and Analysis – [18]

(Grid Filling & Clue-Answer Generation)



5 x 5 Generated Crossword: British Style



1	2	3		
4			5	6
7				
8				
		9		

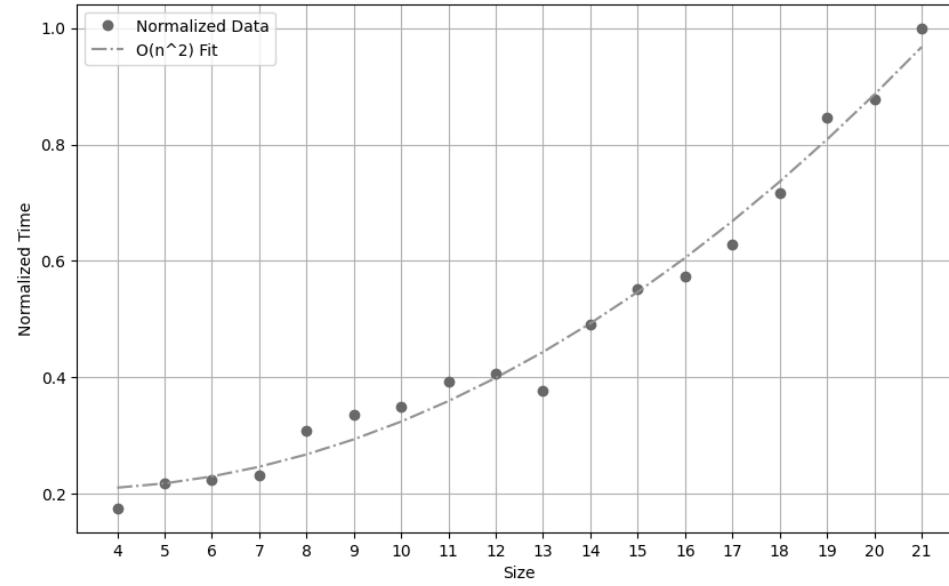
5 x 5 Generated Crossword: American Style

	Across		Down
1.	__ levu, fiji	1	Little bottle
4	At __ (with repercussion)	2	Engagement in days of yore
5	A name for the god of the old testament as transliterated from the hebrew consonants yhvh	3	Hummable, say

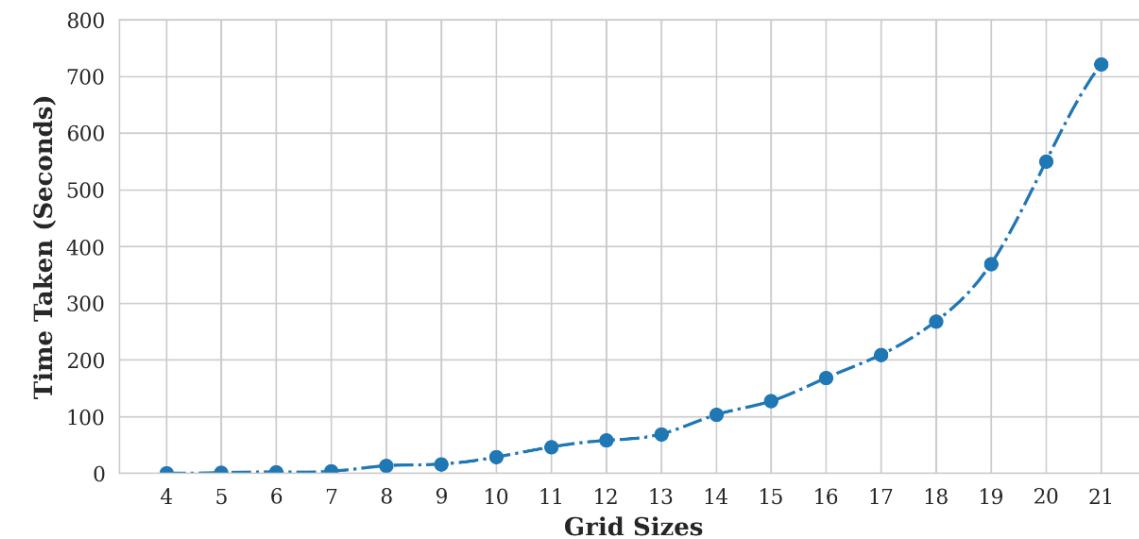
	Across		Down
1	Immigrant's school course	1	Zorba actress kedrova
4	Sting albums " __ winter's night..."	2	Slow-dance movement
7	Laws: latin	3	See 20
8	Silly stuff	5	River of Italy
9	Extremely, to burns	6	Such __ have sown... : lydgate

Results and Analysis— [19] (Time Complexity Plots)

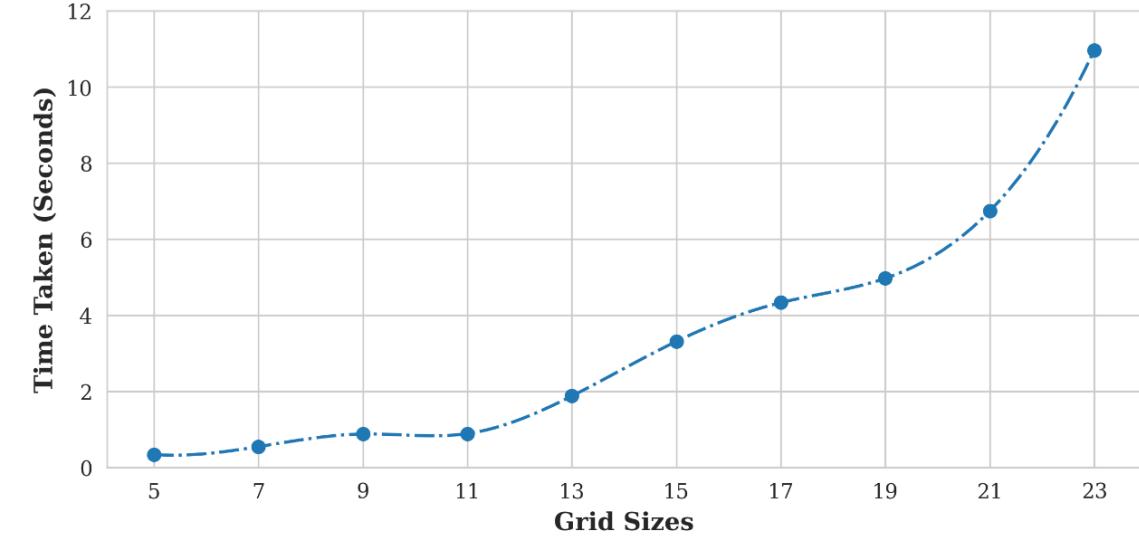
- Grid generator scales quadratically with grid sizes (N) – $O(N^2)$
- American crosswords: $O(2^N)$ time complexity.
- British crosswords: $O(N)$ time complexity.
- American grid filling takes longer than British due to the more engaging and constrained nature of crosswords



Grid Generation Time Plot



Grid Filling Time Plot – American Crosswords



Grid Filling Time Plot – British Crosswords

Results and Analysis – [20] (Landing Page- GUI Interface)

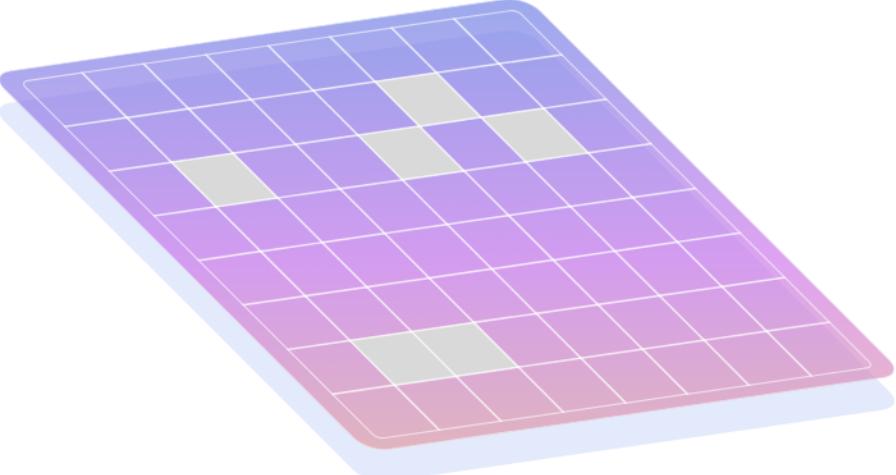
 EZ-Crossword

Home Solver Generator About-Us

Solve and Create Crosswords

Introducing EZ-crossword, your one-stop solution for everything crosswords. Solve your difficult crosswords or generate one to get started.

Solve **Generate**



07/03/2024

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Results and Analysis – [21] (Crossword Solver - GUI Interface)

The screenshot shows the EZ-Crossword website's file uploading interface. 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 illustration of a person holding a large pencil over a crossword grid. On the right, there is a file upload form with a dashed border. Inside the form, the text "Drop files here" is centered, followed by "or", "Choose File", and "scanned-1.jpg". Below these buttons is a "Upload" button. To the right of the file upload form, there are icons for file types: ".Images", ".JSON Files", and ".PUZ Files".

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File Uploading Interface



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

Results and Analysis – [22] (Crossword Solver - GUI Interface)

The image displays two side-by-side screenshots of the EZ-Crossword Solver application interface. Both screenshots show a 15x15 crossword grid with black squares representing empty or filled-in cells. The left screenshot shows the state before correction, while the right screenshot shows the state after correction.

Validation Message: Both screenshots feature a white box at the top center with the heading "Validation" and the instruction "Please validate and correct the detections before proceeding to generate solution." Below this is a "Proceed" button.

Note: Click on grid cells to toggle the color. Edit clues in the text area.

Clues: A sidebar on the right lists the crossword clues, categorized by orientation:

- Across:** 1, 5, 10, 14, 15, 16, 17, 18, 19, 20, 22, 24, 25, 26, 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.

Grid State: In the left screenshot, several clues have their answers partially filled in with red text. In the right screenshot, after correction, the answers for all listed clues are now fully filled in with red text.

Clues and Grid Before Correction

Clues and Grid After Correction

Results and Analysis – [23]

(Crossword Solver - GUI Interface)

EZ-Crossword

Home Solver **Solver** Generator About-Us

Puzzle Solution

Solve Next

The screenshot shows a crossword puzzle grid with various words filled in. To the right, there are two panels: 'Across' and 'Down'. The 'Across' panel lists words like 'Revival', 'Part', 'for the course', 'de cologne', 'Makes changes for the better', 'Plunder', 'Actor – Stoltz', 'Great Greek epic', 'Terrible despot', 'clenched hand', 'Saucer', 'great number', 'Put the ball in ry', 'Hawaiian goose', 'Collections', '12-year-old, for one', and 'Swelled'. The 'Down' panel lists words like 'Doomsayer', 'Noggin', 'Offering fun', 'Periods', '-- of the worlds', 'heavy', 'some wines', 'port in Pennsylvania', 'rant and --', 'say with confidence', 'woody stem', 'was on to', and 'anger'.

Solver Generated Solution

PREVIOUS PUZZLE SOLVED



Newspaper Provided Solution

Results and Analysis – [24] (Crossword Generator – GUI Interface)

Grid Dimensions

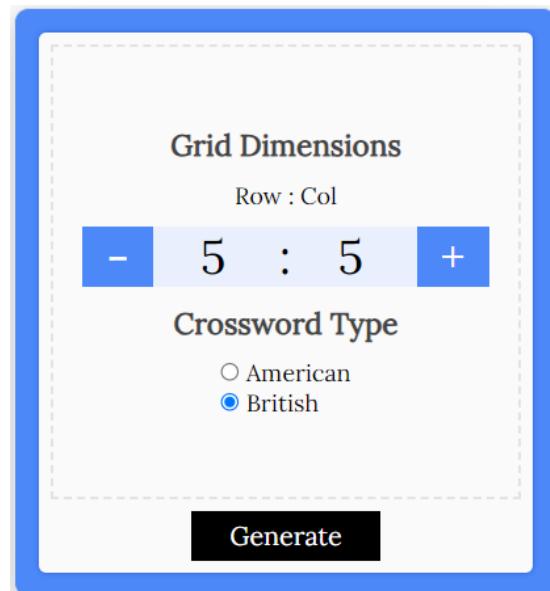
Row : Col

- 5 : 5 +

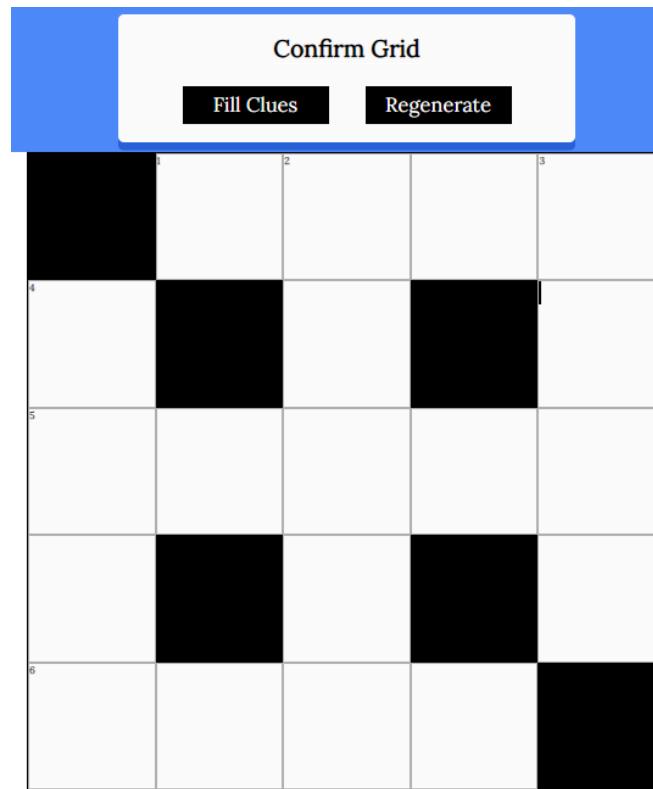
Crossword Type

American
 British

Generate



Grid Generator Interface

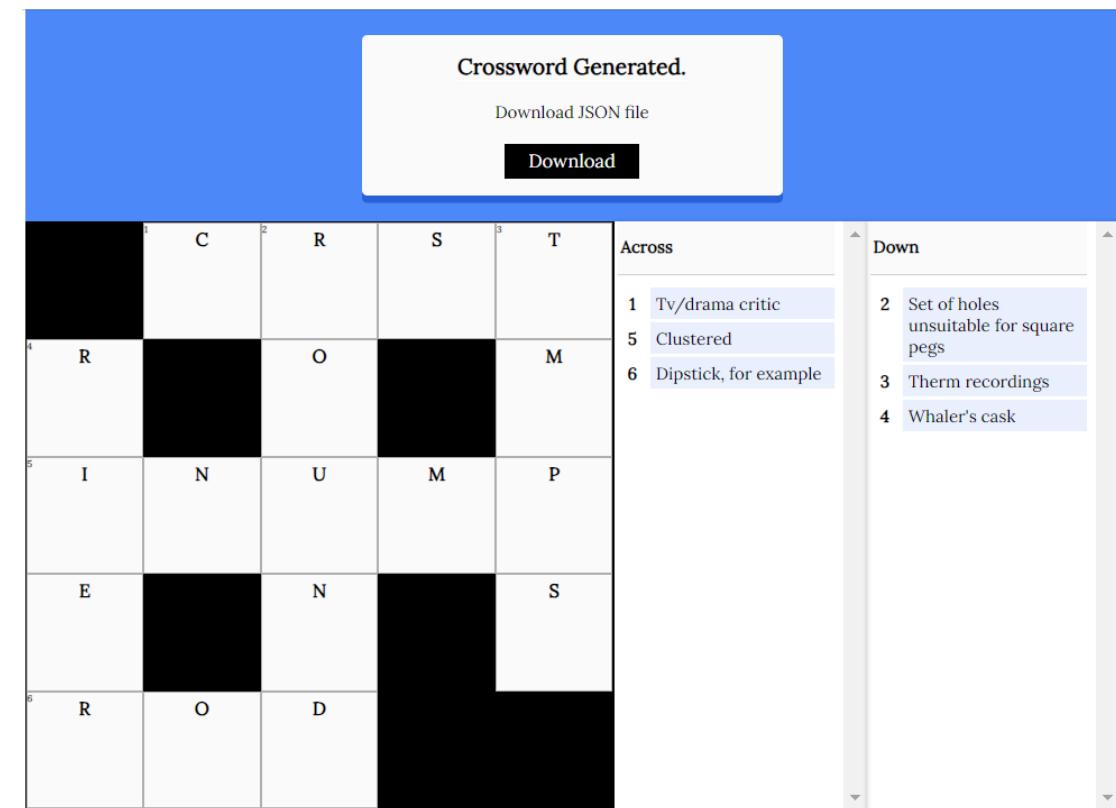


Generated Grid

Crossword Generated.

Download JSON file

Download



	1 C	2 R	3 S	4 T
4 R		O		M
5 I	N	U	M	P
E		N		S
6 R	O	D		

Across

1 Tv/drama critic
5 Clustered
6 Dipstick, for example

Down

2 Set of holes unsuitable for square pegs
3 Therm recordings
4 Whaler's cask

Generated Crossword Puzzle

Future Enhancements

- Improving Vision Pipeline
 - Use of deep learning to segment newspaper for extracting columns and clues.
- Crossword Solving
 - Integration of LLMs for answer generation.
- Crossword Generation
 - Utilization of path consistency for enhancing constraint propagation.
- Web App Improvement
 - Provision of clear feedback and live solving/generating progress bar.

Conclusion

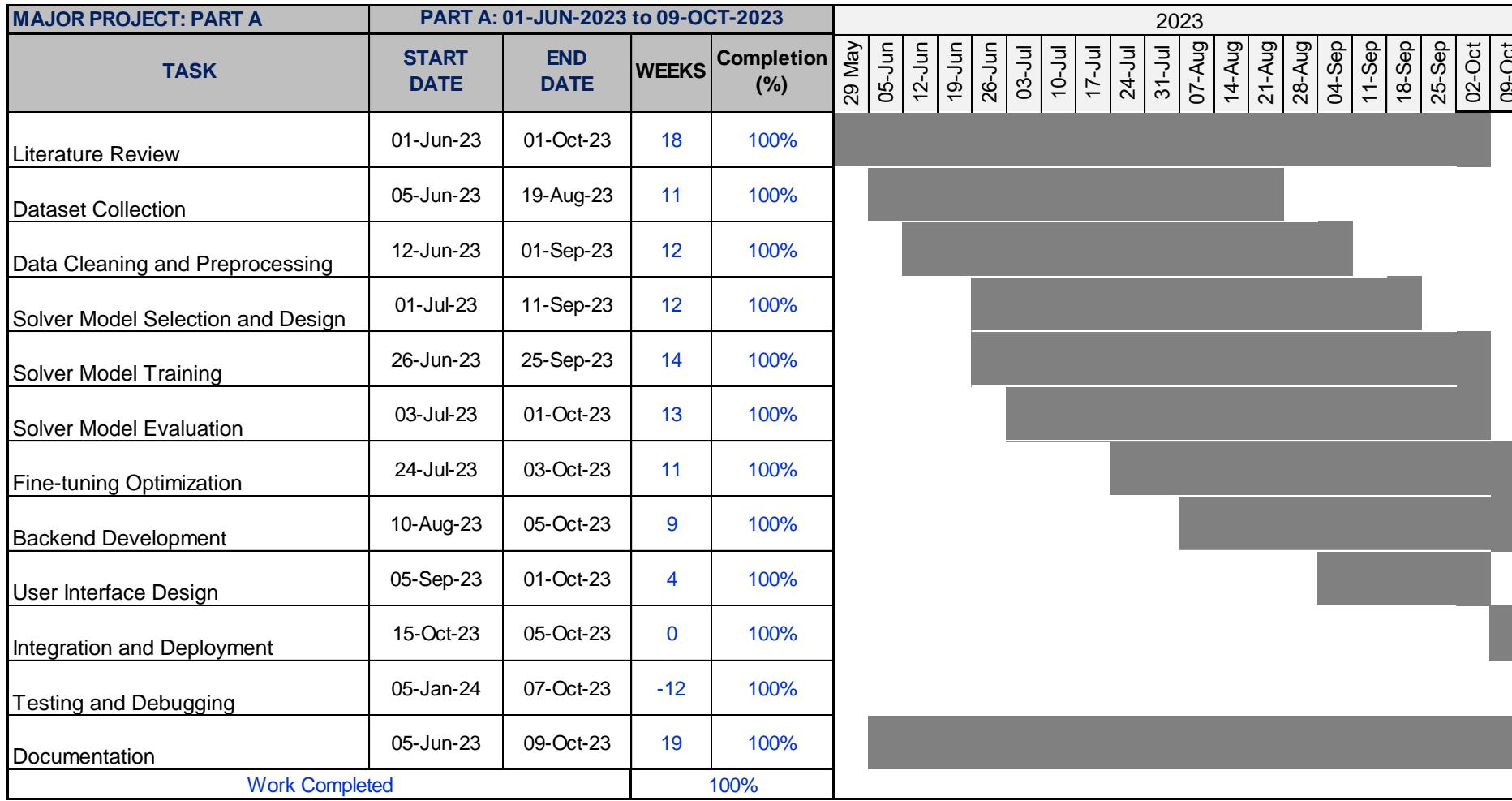
- Created a computer program that can solve crosswords of different difficulty levels.
- Developed a versatile AI system for generating diverse crossword puzzles.
- Deployed a web app that facilitates both crossword solving and generation.
- Contributed to the field of automatically solving and generating crosswords.

Project Budget

S.N	Particulars	Cost
1.	Dollar Card Expenses	Rs. 2,500
2.	Miscellaneous (Printing and Binding)	Rs. 20,000
	Total	Rs. 22,500

Project Schedule

(Timeline - Part A)



Project Schedule

(Timeline - Part B)

MAJOR PROJECT: PART B	PART B: 17-NOV-2023 to 29-FEB-2024				Completion (%)	2023							2024								
	TASK	START DATE	END DATE	WEEKS		13 Nov	20-Nov	27-Nov	04-Dec	11-Dec	18-Dec	25-Dec	01-Jan	08-Jan	15-Jan	22-Jan	29-Jan	05-Feb	12-Feb	19-Feb	26-Feb
Literature Review	17-Nov-23	30-Dec-23	7	100%																	
Grid Generation Algorithm Development	20-Nov-23	16-Jan-24	9	100%																	
Generator Model Selection and Design	27-Nov-23	01-Feb-24	10	100%																	
Generator Model Training	30-Nov-23	10-Feb-24	11	100%																	
Generator Model Evaluation	03-Jul-23	15-Feb-24	33	100%																	
Fine-tuning Optimization	15-Dec-23	20-Feb-24	11	100%																	
Backend Development	20-Nov-23	26-Jan-24	10	100%																	
User Interface Design	25-Nov-23	10-Jan-24	8	100%																	
Integration and Deployment	30-Nov-23	25-Feb-24	13	100%																	
Testing and Debugging	05-Jan-24	26-Feb-24	9	100%																	
Documentation	17-Nov-23	29-Feb-24	16	100%																	
Work Completed				100%																	

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Thank You!