

# Understanding Numba

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<https://anaconda.com>

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Version: c6ffd8e28c <https://github.com/esc/numba-talk>



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# Outline

- 1 Introduction
- 2 Going Deeper
- 3 NumPy Support
- 4 Tips and Tricks
- 5 Summary?

# Numba in a Nutshell

- A compiler that might make your code faster
- Requires importing a decorator
- And decorating functions with it
- Numba = NumPy + Mamba (fast snake)

# Numba Explained

- Numba is a
  - just-in-time
  - type-specializing
  - function compiler
  - for accelerating numerically-focused Python

- LLVM is a compiler toolkit
- Numba uses it as a compiler backend
- Access via `llvmlite`

# Example

- Sieve of Erasthenes

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11	12	13	14	15	16	17	18	19	20	2
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	2
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	



# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	2
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	2
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	2   3
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	2   3
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	2   3
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	2   3
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	2   3
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	2   3
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	



# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers 2   3
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers 2   3
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
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81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	2
31	32	33	34	35	36	37	38	39	40	3
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Erasthothenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	2
31	32	33	34	35	36	37	38	39	40	3
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	2   3
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	2
31	32	33	34	35	36	37	38	39	40	3
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	2   3
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	2
31	32	33	34	35	36	37	38	39	40	3
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	



# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	2
31	32	33	34	35	36	37	38	39	40	3
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	2
31	32	33	34	35	36	37	38	39	40	3
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	2
31	32	33	34	35	36	37	38	39	40	3
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

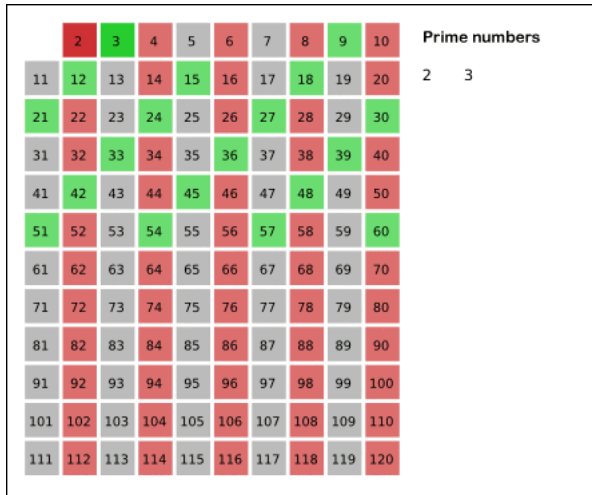
# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	2
31	32	33	34	35	36	37	38	39	40	3
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes



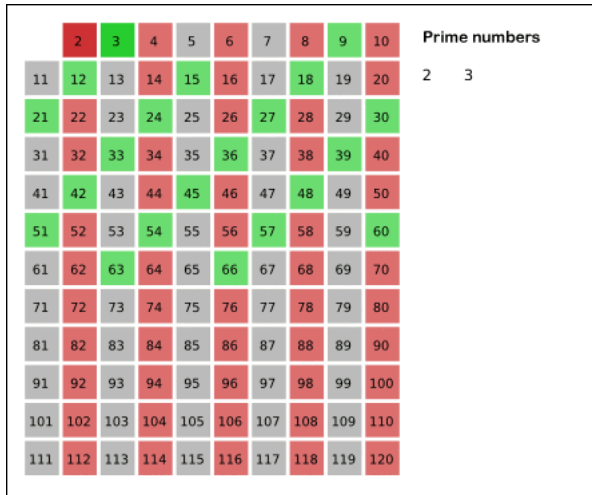
# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers 2   3
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
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111	112	113	114	115	116	117	118	119	120	

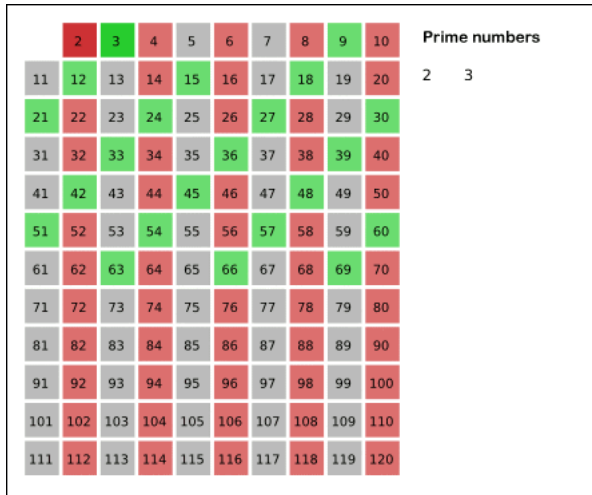
# Example

- Sieve of Eratosthenes



# Example

- Sieve of Eratosthenes





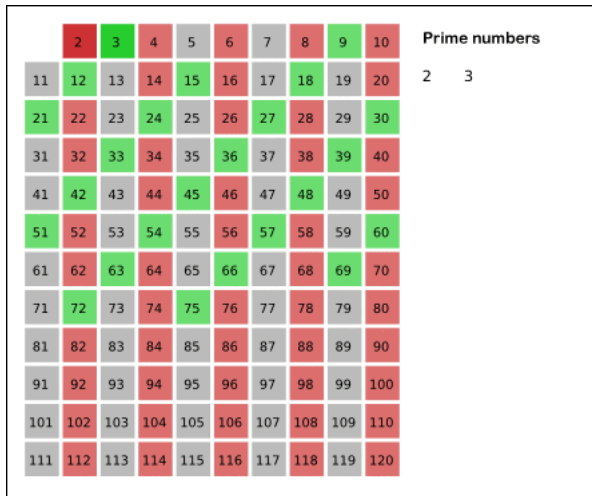
# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers 2   3
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

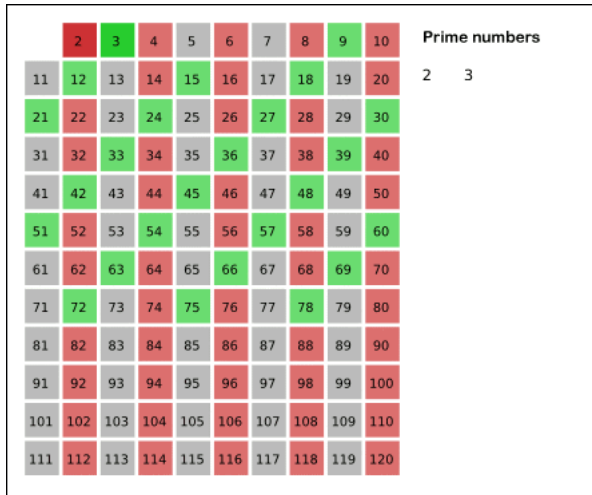
# Example

- Sieve of Eratosthenes



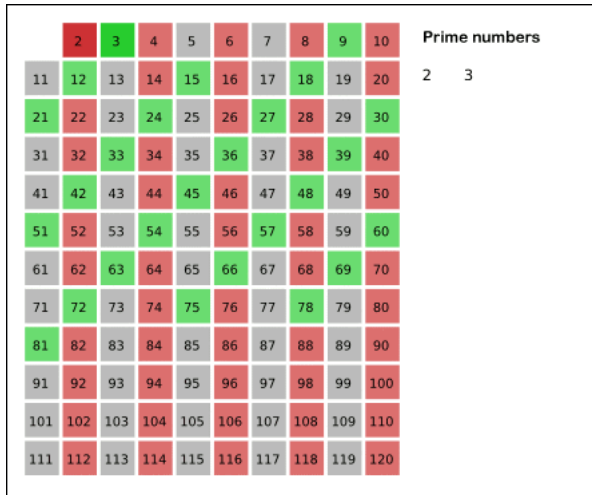
# Example

- Sieve of Eratosthenes



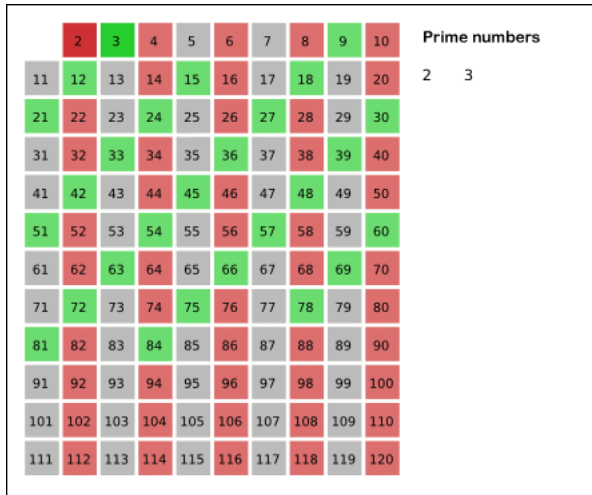
# Example

- Sieve of Eratosthenes



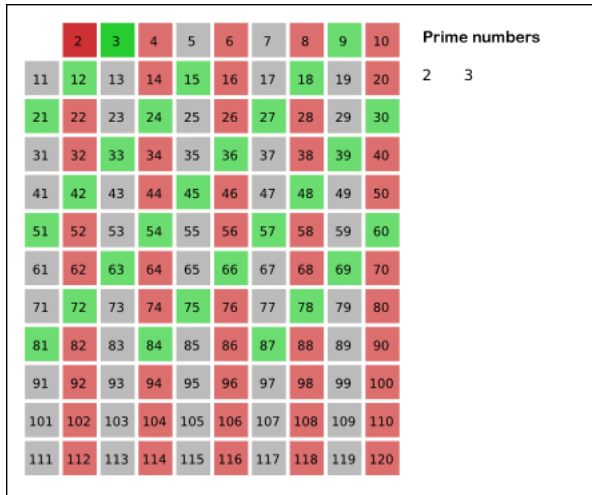
# Example

- Sieve of Eratosthenes



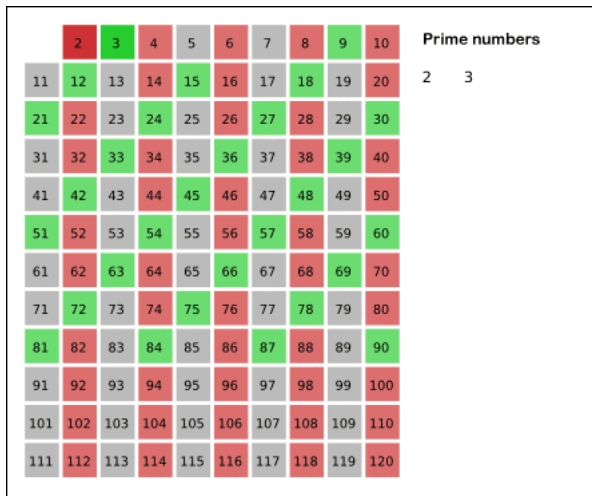
# Example

- Sieve of Eratosthenes



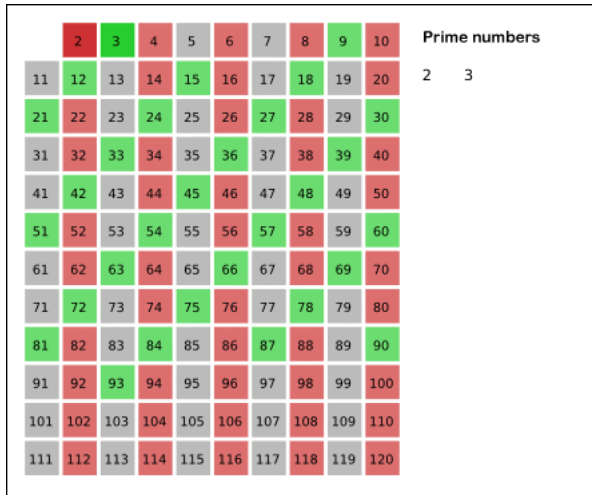
# Example

- Sieve of Eratosthenes



# Example

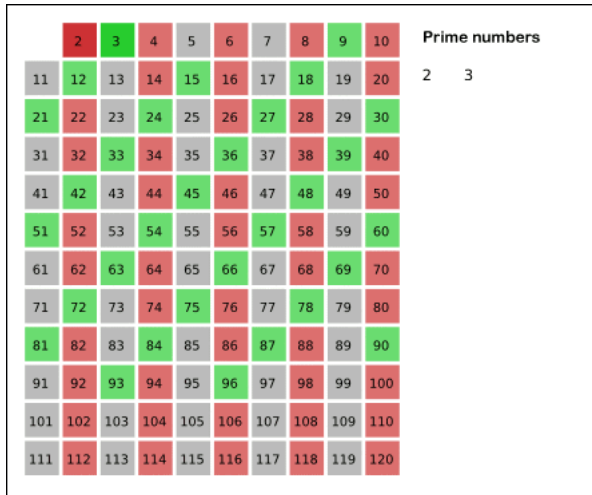
- Sieve of Eratosthenes





# Example

- Sieve of Eratosthenes



# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers 2   3
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

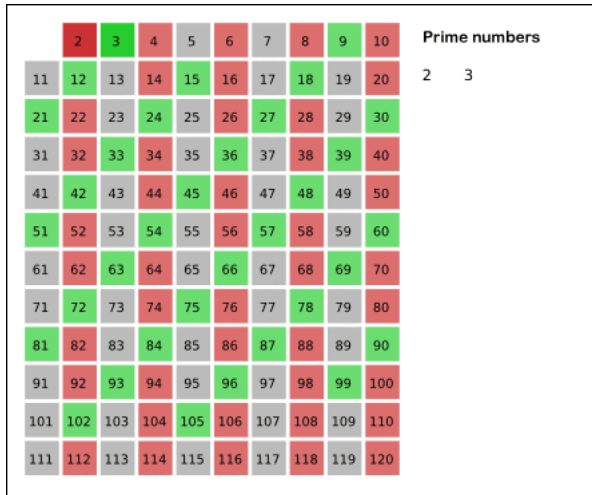
# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	2   3
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
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111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes



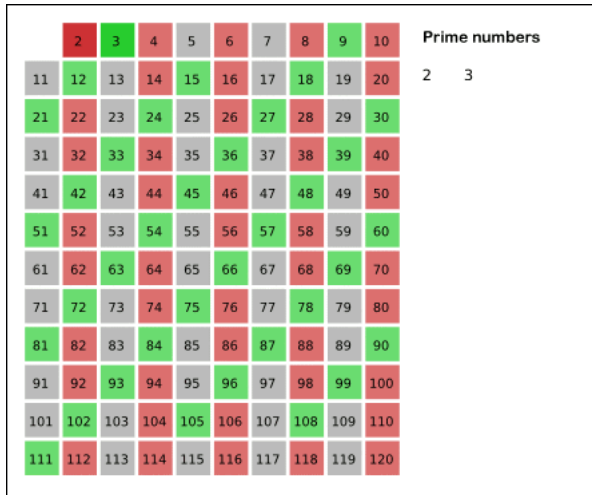
# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	2
31	32	33	34	35	36	37	38	39	40	3
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
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111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes



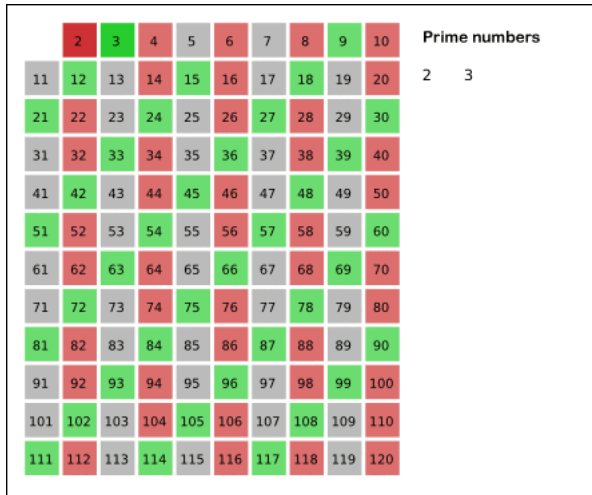
# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	2
31	32	33	34	35	36	37	38	39	40	3
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes





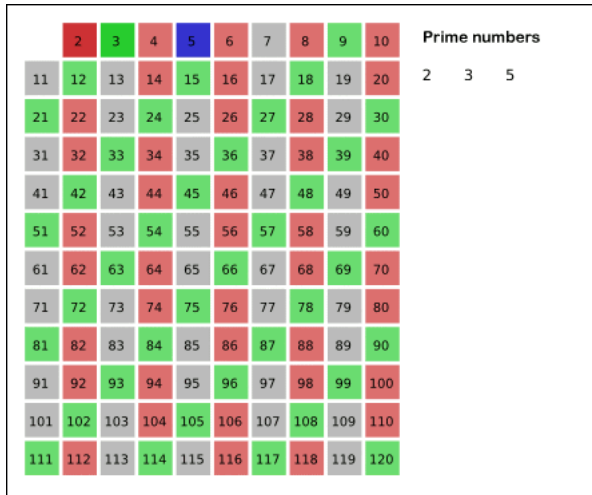
# Example

- Sieve of Eratosthenes

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11	12	13	14	15	16	17	18	19	20	2   3
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
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91	92	93	94	95	96	97	98	99	100	
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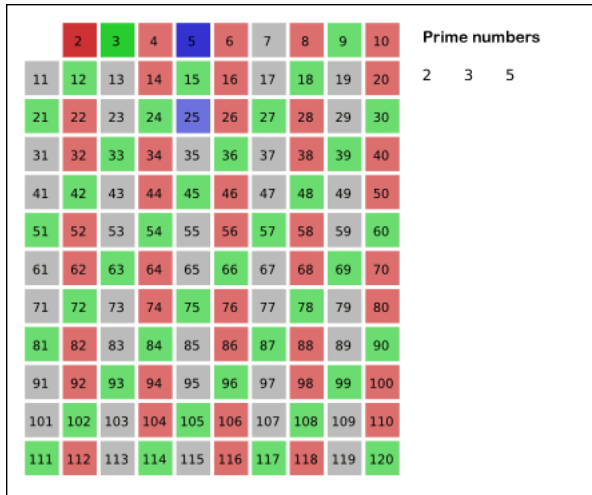
# Example

- Sieve of Eratosthenes



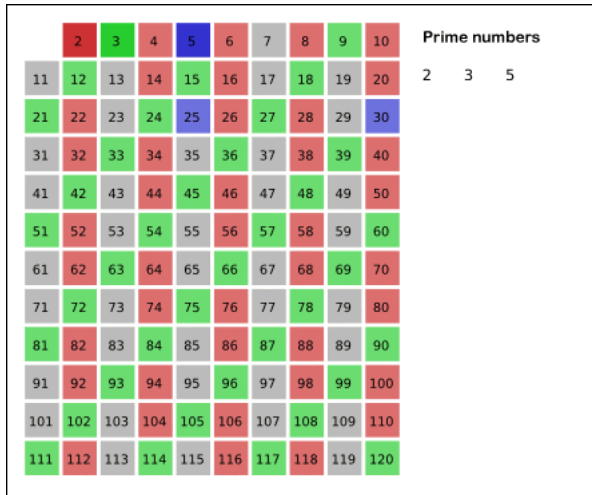
# Example

- Sieve of Eratosthenes



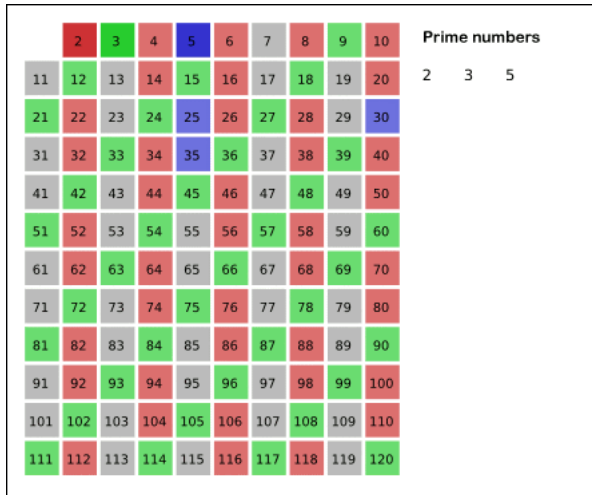
# Example

- Sieve of Eratosthenes



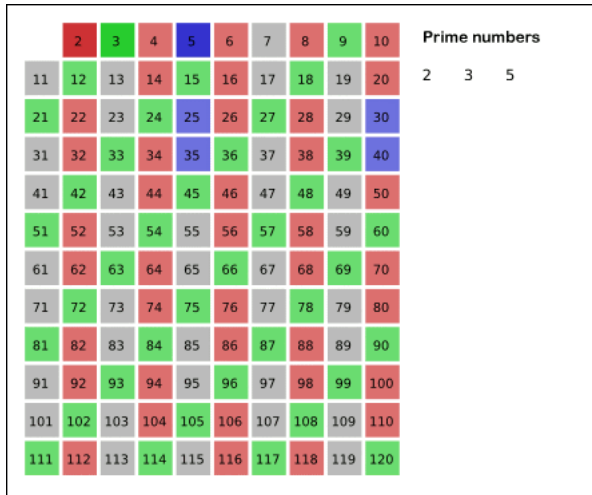
# Example

- Sieve of Eratosthenes



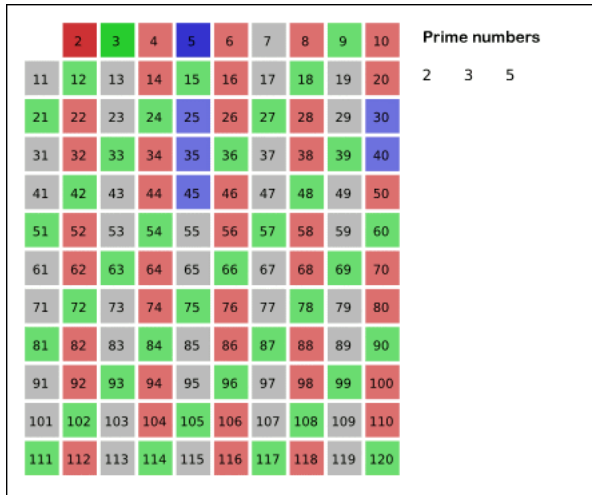
# Example

- Sieve of Eratosthenes



# Example

- Sieve of Eratosthenes



# Example

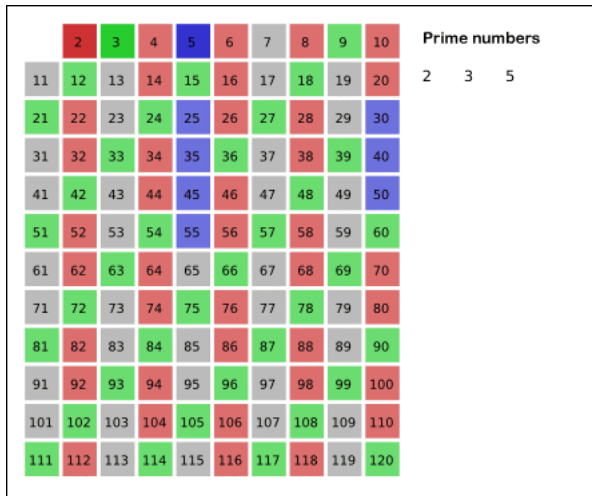
- Sieve of Erasthothenes

	2	3	4	5	6	7	8	9	10	Prime numbers 2   3   5
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
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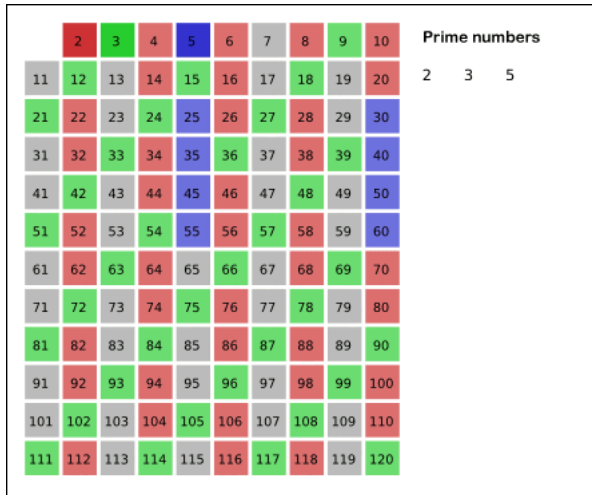
# Example

- Sieve of Eratosthenes



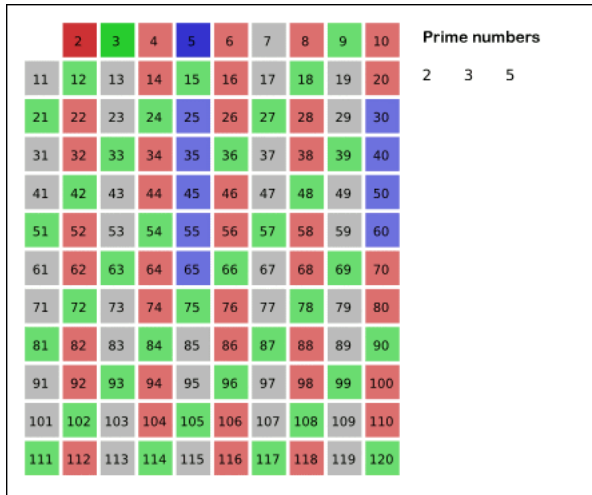
# Example

- Sieve of Eratosthenes



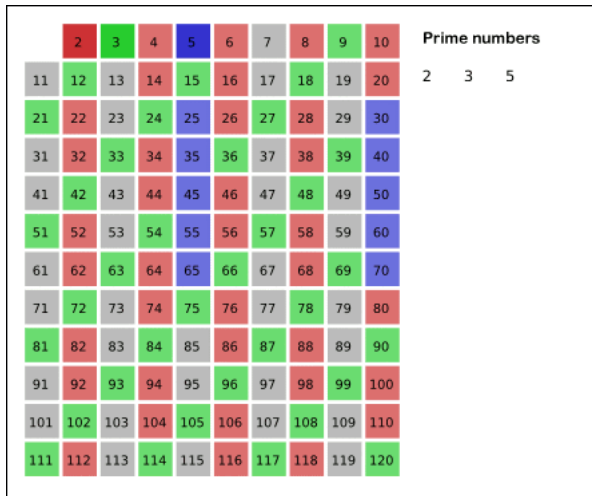
# Example

- Sieve of Eratosthenes



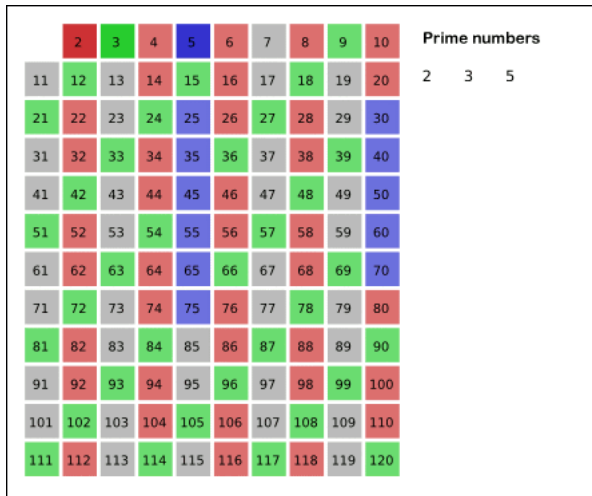
# Example

- Sieve of Eratosthenes



# Example

- Sieve of Eratosthenes



# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers 2   3   5
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

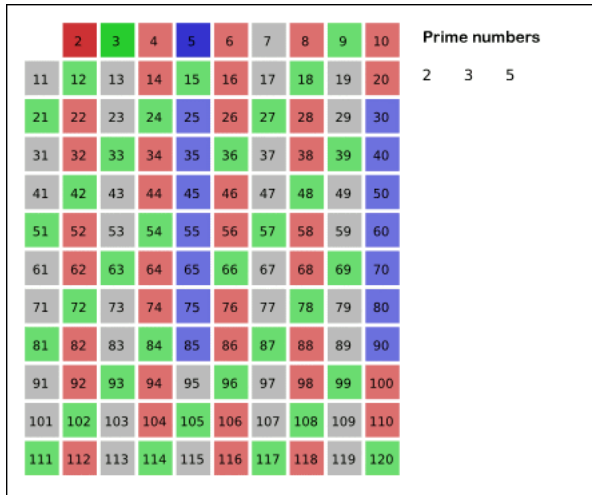
# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers 2    3    5
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

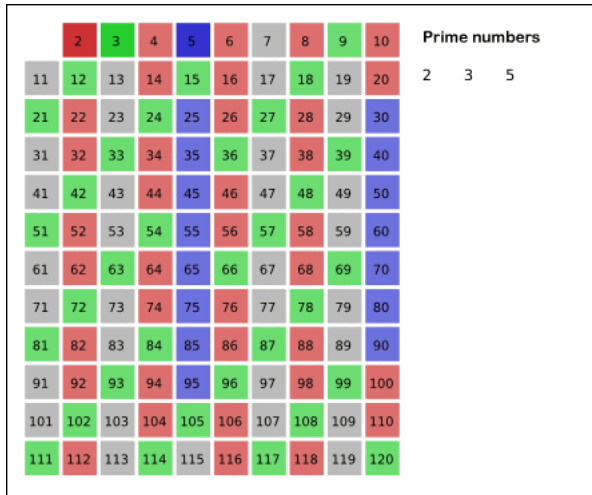
- Sieve of Eratosthenes





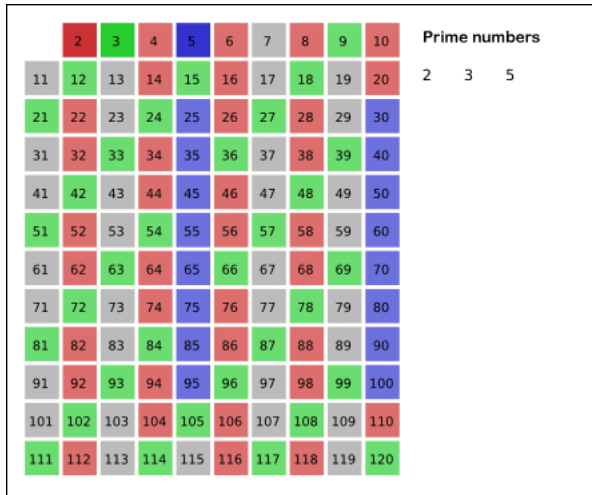
# Example

- Sieve of Eratosthenes



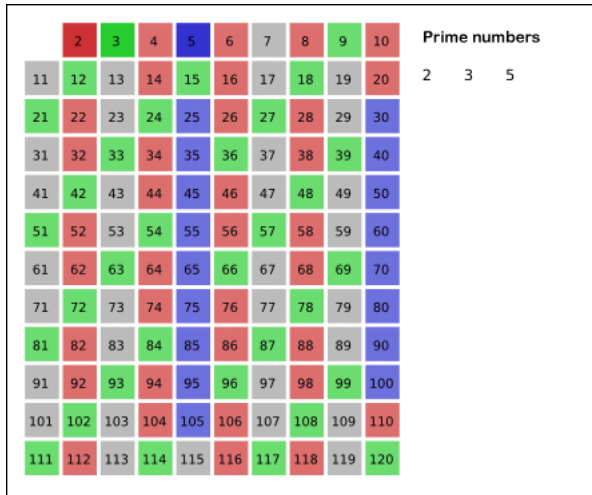
# Example

- Sieve of Eratosthenes



# Example

- Sieve of Eratosthenes



# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers 2   3   5
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
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91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers 2   3   5
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers 2    3    5
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers			
11	12	13	14	15	16	17	18	19	20	2	3	5	7
21	22	23	24	25	26	27	28	29	30				
31	32	33	34	35	36	37	38	39	40				
41	42	43	44	45	46	47	48	49	50				
51	52	53	54	55	56	57	58	59	60				
61	62	63	64	65	66	67	68	69	70				
71	72	73	74	75	76	77	78	79	80				
81	82	83	84	85	86	87	88	89	90				
91	92	93	94	95	96	97	98	99	100				
101	102	103	104	105	106	107	108	109	110				
111	112	113	114	115	116	117	118	119	120				

# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers			
11	12	13	14	15	16	17	18	19	20	2	3	5	7
21	22	23	24	25	26	27	28	29	30				
31	32	33	34	35	36	37	38	39	40				
41	42	43	44	45	46	47	48	49	50				
51	52	53	54	55	56	57	58	59	60				
61	62	63	64	65	66	67	68	69	70				
71	72	73	74	75	76	77	78	79	80				
81	82	83	84	85	86	87	88	89	90				
91	92	93	94	95	96	97	98	99	100				
101	102	103	104	105	106	107	108	109	110				
111	112	113	114	115	116	117	118	119	120				



# Example

- Sieve of Erasthothenes

	2	3	4	5	6	7	8	9	10	Prime numbers 2   3   5   7
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
71	72	73	74	75	76	77	78	79	80	
81	82	83	84	85	86	87	88	89	90	
91	92	93	94	95	96	97	98	99	100	
101	102	103	104	105	106	107	108	109	110	
111	112	113	114	115	116	117	118	119	120	

# Example

- Sieve of Erasthothenes

	2	3	4	5	6	7	8	9	10	Prime numbers			
11	12	13	14	15	16	17	18	19	20	2	3	5	7
21	22	23	24	25	26	27	28	29	30				
31	32	33	34	35	36	37	38	39	40				
41	42	43	44	45	46	47	48	49	50				
51	52	53	54	55	56	57	58	59	60				
61	62	63	64	65	66	67	68	69	70				
71	72	73	74	75	76	77	78	79	80				
81	82	83	84	85	86	87	88	89	90				
91	92	93	94	95	96	97	98	99	100				
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111	112	113	114	115	116	117	118	119	120				

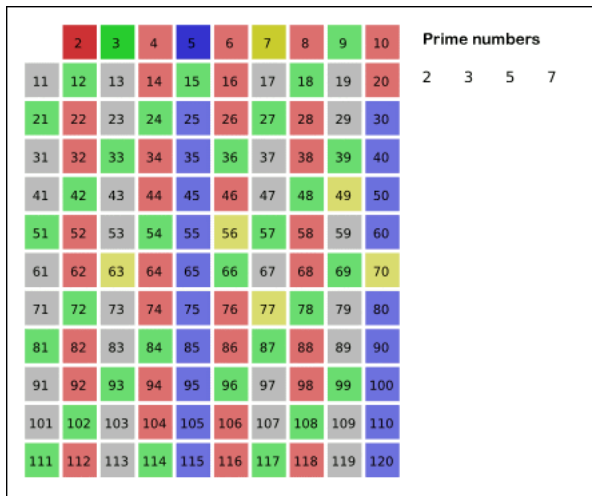
# Example

- Sieve of Eratosthenes

	2	3	4	5	6	7	8	9	10	Prime numbers 2   3   5   7
11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	
31	32	33	34	35	36	37	38	39	40	
41	42	43	44	45	46	47	48	49	50	
51	52	53	54	55	56	57	58	59	60	
61	62	63	64	65	66	67	68	69	70	
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91	92	93	94	95	96	97	98	99	100	
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# Example

- Sieve of Eratosthenes



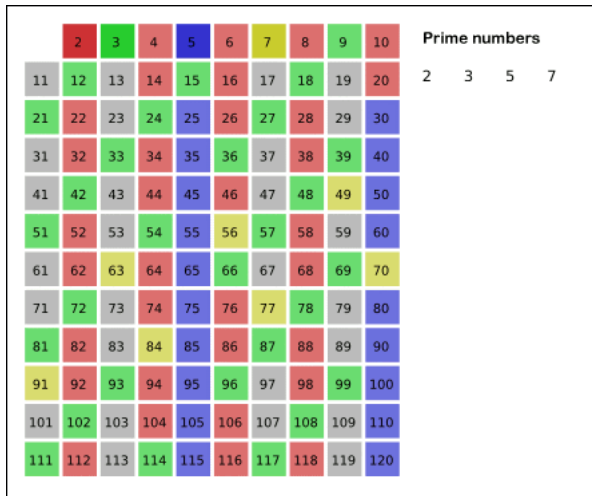
# Example

- Sieve of Erasthothenes

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21	22	23	24	25	26	27	28	29	30	
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41	42	43	44	45	46	47	48	49	50	
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91	92	93	94	95	96	97	98	99	100	
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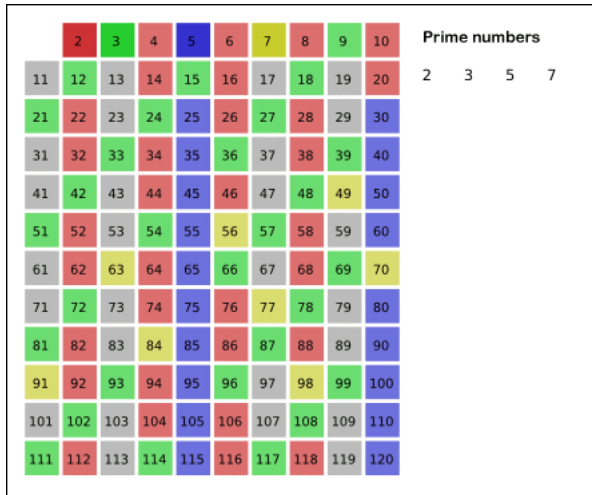
# Example

- Sieve of Eratosthenes



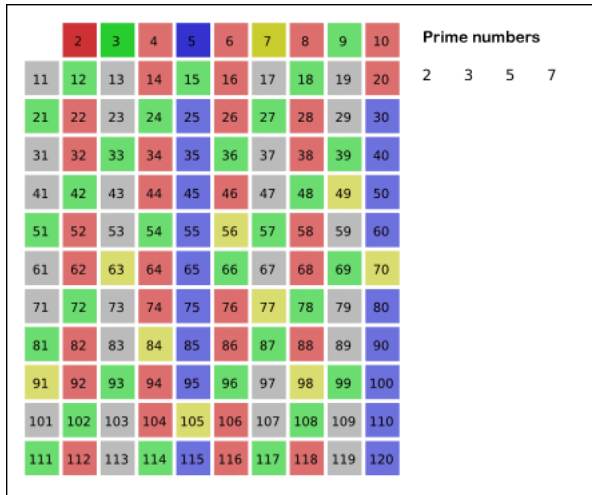
# Example

- Sieve of Eratosthenes



# Example

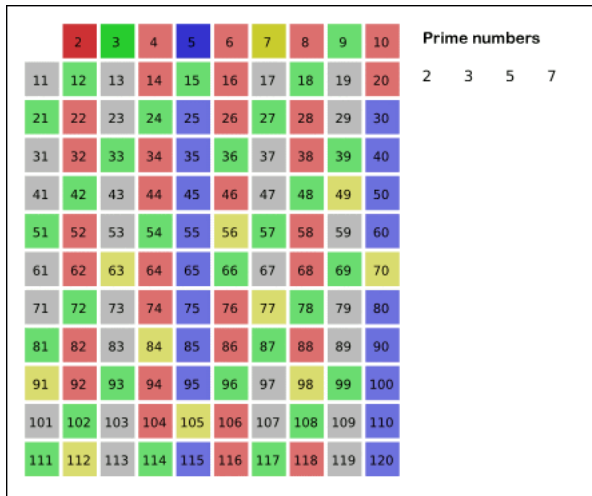
- Sieve of Eratosthenes





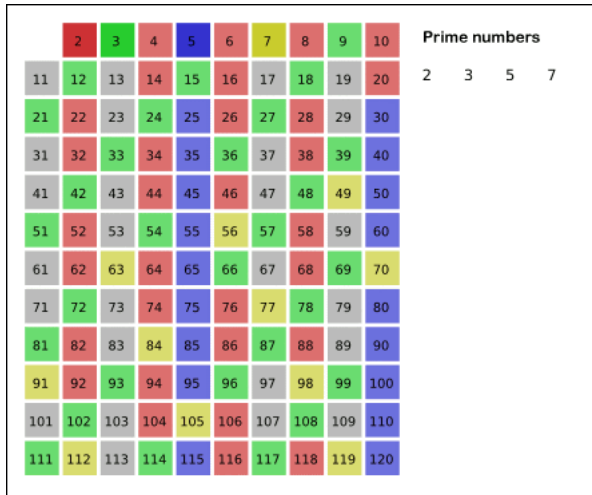
# Example

- Sieve of Eratosthenes



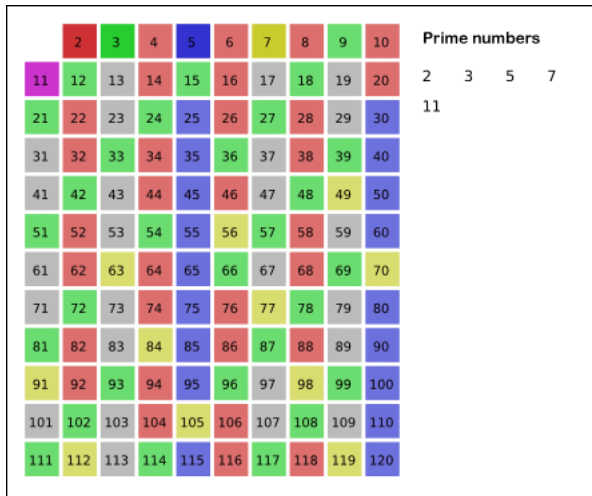
# Example

- Sieve of Eratosthenes



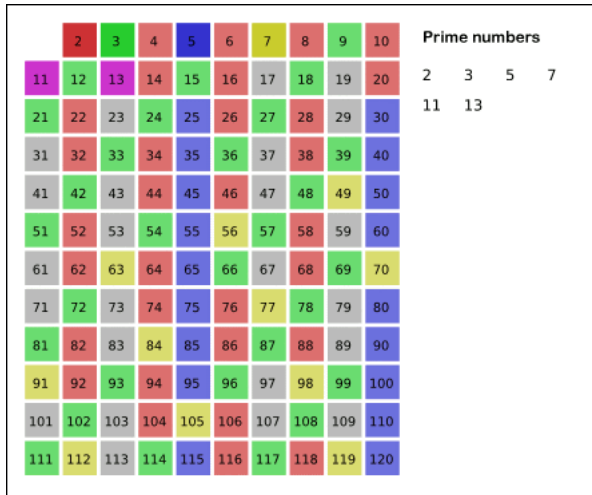
# Example

- Sieve of Eratosthenes



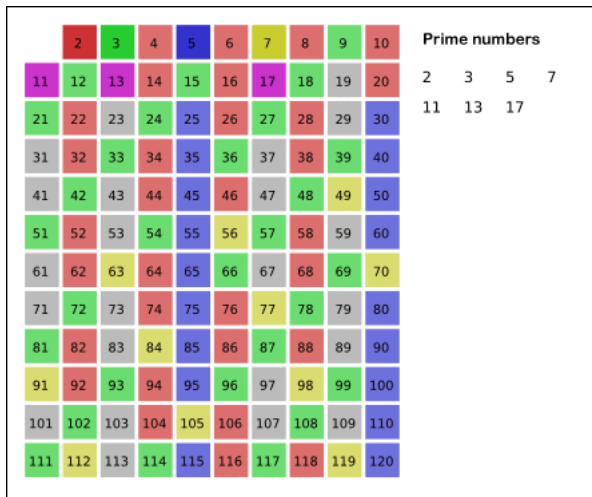
# Example

- Sieve of Eratosthenes



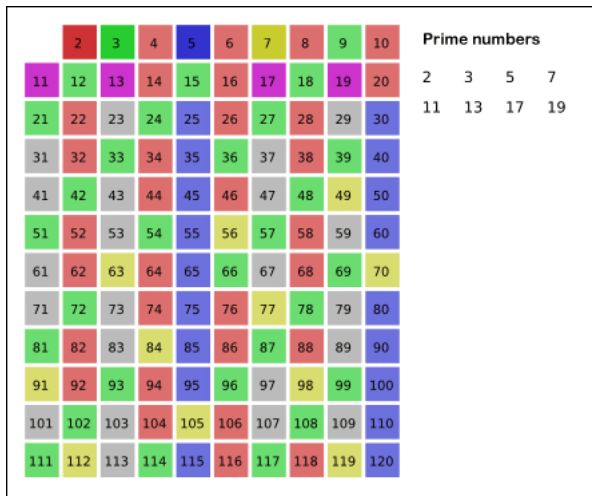
# Example

- Sieve of Eratosthenes



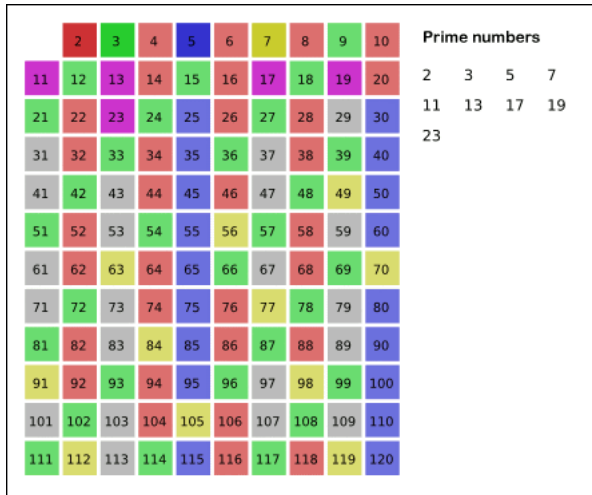
# Example

- Sieve of Eratosthenes



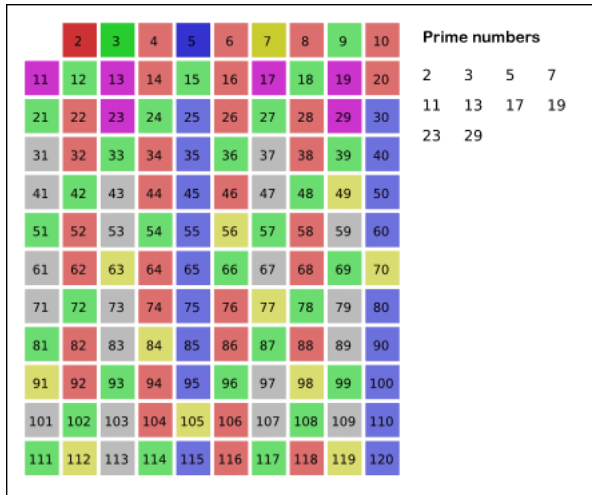
# Example

- Sieve of Eratosthenes



# Example

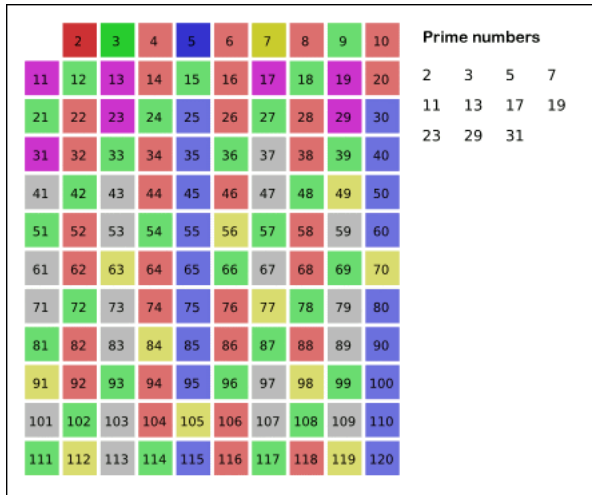
- Sieve of Eratosthenes





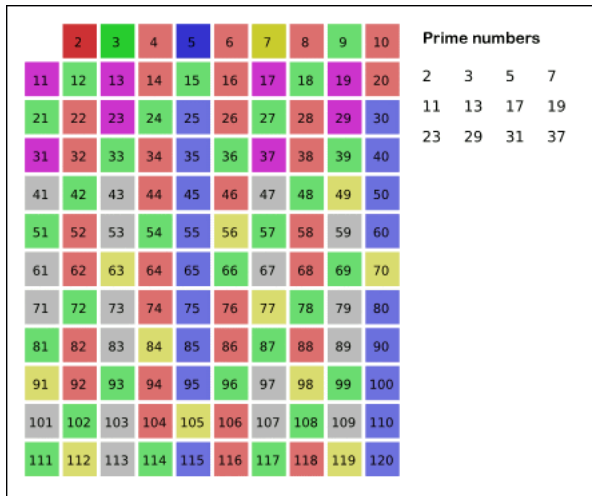
# Example

- Sieve of Eratosthenes



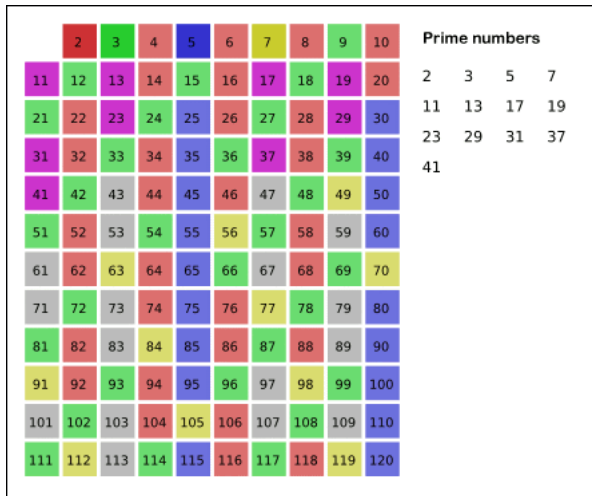
# Example

- Sieve of Eratosthenes



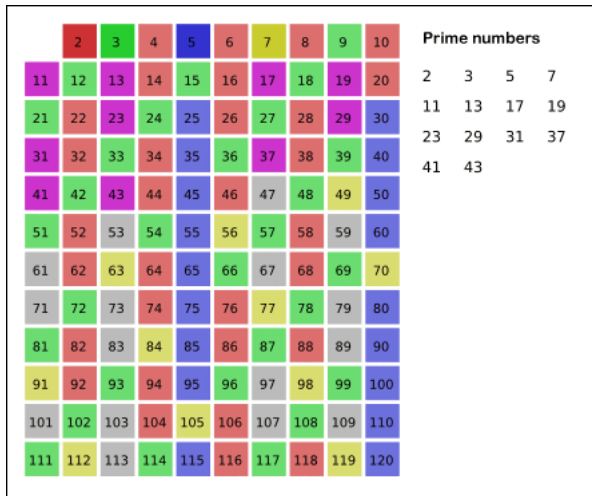
# Example

- Sieve of Eratosthenes



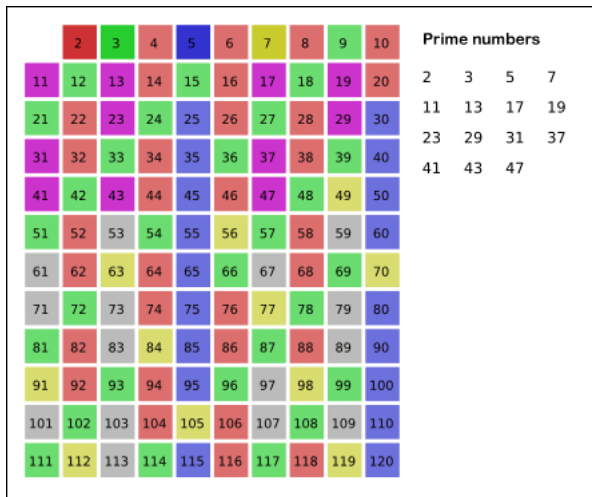
# Example

- Sieve of Eratosthenes



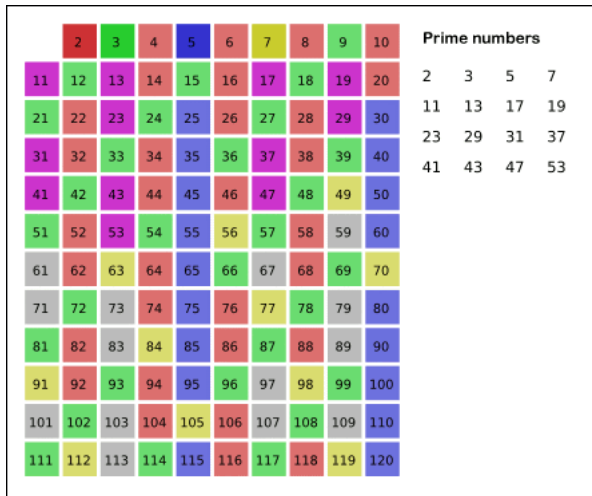
# Example

- Sieve of Eratosthenes



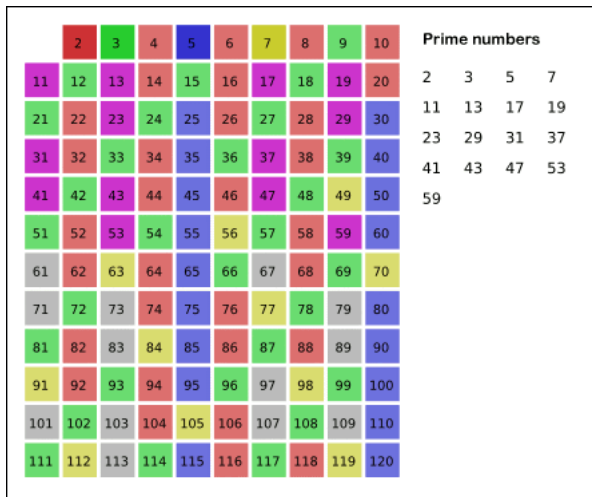
# Example

- Sieve of Eratosthenes



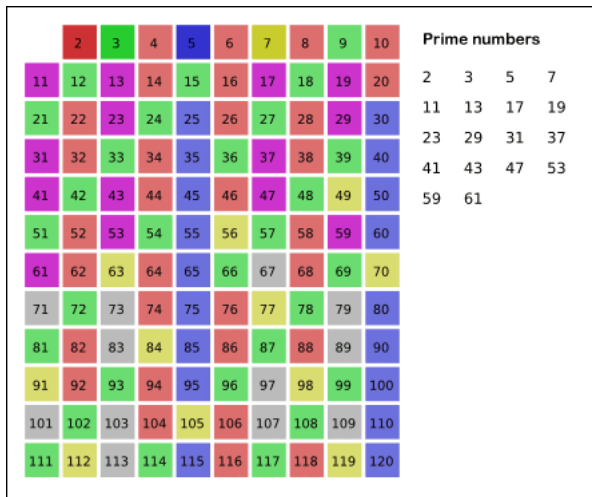
# Example

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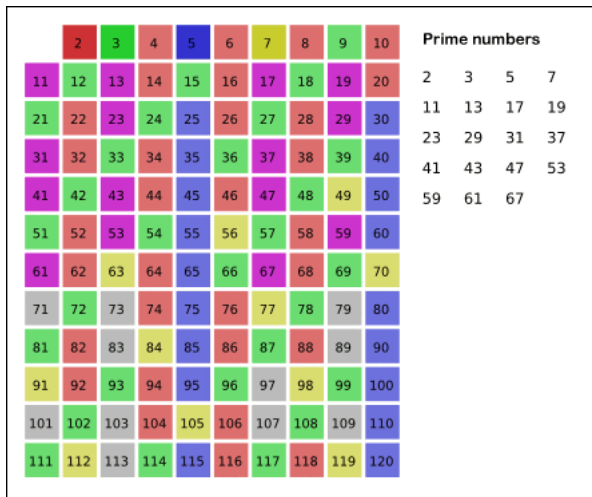
- Sieve of Eratosthenes





# Example

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# Example

- Sieve of Eratosthenes

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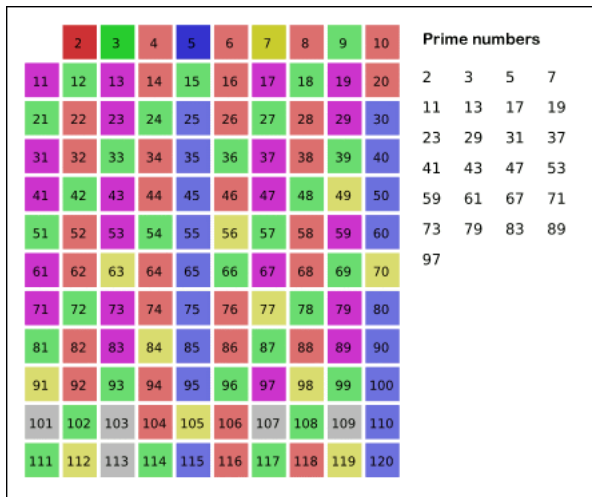
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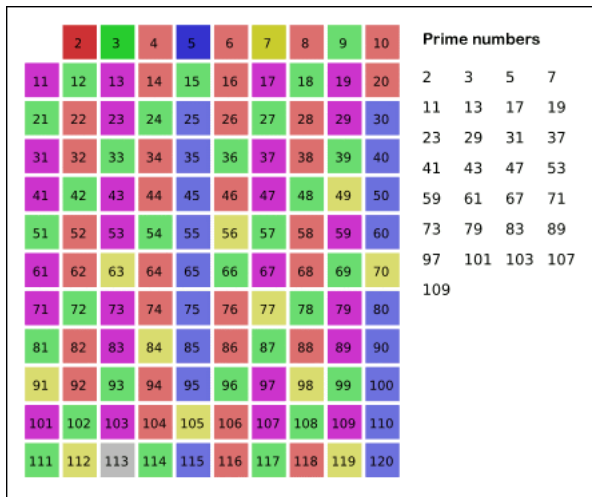
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# Example

```
import numpy as np
import numba as nb

@nb.njit # simply add the njit decorator
def primes(max=100000):
    numbers = np.ones(max, dtype=np.uint8) # initialize the boolean sieve
    for i in range(2, max):
        if numbers[i] == 0: # has previously been crossed off
            continue
        else: # it is a prime, cross off all multiples
            x = i + i
            while x < max:
                numbers[x] = 0
                x += i
    # return all primes, as indicated by all boolean positions that are one
    return np.nonzero(numbers)[0][2:]
```

# Example

```
In [5]: %timeit sieve.primes.py_func()
124 ms ± 2.72 ms per loop (mean ± std. dev. of 7 runs, 10 loops each)

In [6]: %timeit sieve.primes()
308 µs ± 8.93 µs per loop (mean ± std. dev. of 7 runs, 1000 loops each)
```

# Open Source Status

- Several companies and many open source contributors
  - 4 FTE funded to contribute to Numba between Anaconda, Intel, Quansight, and others
  - 7-12 non-core contributors per release ( every 2 months)
- Slowly moving towards NumFocus application
- Issue and PR lists growing

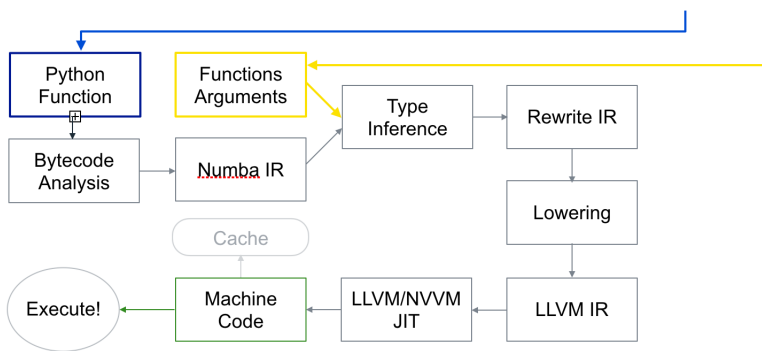
# Outline

- 1 Introduction
- 2 Going Deeper
- 3 NumPy Support
- 4 Tips and Tricks
- 5 Summary?



# Numba Flow

```
@jit
def do_math(a, b):
    ...
>>> do_math(x, y)
```



# Internals

- Translate Python objects of supported types into representations with no CPython dependencies ("unboxing")
- Compile Python bytecode from your decorated function into machine code.
- Swap calls to builtins and NumPy functions for implementations provided by Numba (or 3rd party Numba extensions)
- Allow LLVM to inline functions, autovectorize loops, and do other optimizations you would expect from a C compiler
- Allow LLVM to exploit all supported instruction sets of your hardware (SSE, AVX)
- When calling the function, release the GIL if requested
- Convert return values back to Python objects ("boxing")

# What Numba does not do

- Automated translation of CPython or NumPy implementations
- Automatic compilation of 3rd party libraries
- Partial compilation
- Automatic conversion of arbitrary Python types
- Change the layout of data allocated in the interpreter
- Translate entire programs
- Magically make individual NumPy functions faster

## When is Numba unlikely to help?

- Whole program compilation
- Critical functions have already been converted to C or optimized Cython
- Need to interface directly to C++
- Algorithms are not primarily numerical
- Exception: Numba can do pretty well at bit manipulation

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# Implementing Numpy

- Numba does not use any of the NumPy C implementations
- We implement the NumPy API using Numba compatible/supported Python
- Treat Numpy as DSL for array oriented computing

# Implementing Numpy

- Implement: `numpy.linalg.norm`
- For vectors, ord is:
  - `inf`  $\rightarrow$  `min(abs(x))`
  - `0`  $\rightarrow$  `sum(x != 0)`
- Implemented in: `numba.targets.linalg.py`

# Implementing Numpy

```
elif ord == -np.inf:
    # min(abs(a))
    ret = abs(a[0])
    for k in range(1, n):
        val = abs(a[k])
        if val < ret:
            ret = val
    return ret

elif ord == 0:
    # sum(a != 0)
    ret = 0.0
    for k in range(n):
        if a[k] != 0.:
            ret += 1.
    return ret
```



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# Tips and Tricks

- Always use `jit(nopython=True)`
- (Or `njit`)
- Prefer Numpy arrays for numerical data
- Use typed containers from `numba.typed` for nested data
- Use small functions, they are inlined
- `for` loops are fine
- Array expressions are fused, so those are fine too

# Typed Containers

```
from numba import njit
from numba.typed import List

l = List()  # instantiate a new typed list
l1 = List(); [l1.append(i) for i in range(5)]
l.append(l1)  # add the first sub-list
l2 = List(); [l2.append(i) for i in range(10)]
l.append(l2)  # add the second sub-list
print(l)

@njit
def func(my_list):
    # modify list in a compiled context
    for i in range(10):
        my_list[1][i] = 23

func(l)
print(l)
```

# Typed Containers

```
$ python code/typed.py  
[[0, 1, 2, 3, 4], [0, 1, 2, 3, 4, 5, 6, 7, 8, 9]]  
[[0, 1, 2, 3, 4], [23, 23, 23, 23, 23, 23, 23, 23, 23, 23]]
```

# Fused Expressions

```
import numpy as np
from numba import njit

a, b = np.arange(1e6), np.arange(1e6)

@njit
def func(a, b):
    return a*b-4.1*a > 2.5*b
```

# Fused Expressions

```
In [1]: from fused import a,b,func
```

```
In [2]: %timeit func.py_func(a,b)
```

```
4.68 ms ± 89.7 µs per loop (mean ± std. dev. of 7 runs, 100 loops each)
```

```
In [3]: %timeit func(a,b)
```

```
626 µs ± 22.4 µs per loop (mean ± std. dev. of 7 runs, 1000 loops each)
```

- Windows 7 and later, 32 and 64-bit
- macOS 10.9 and later, 64-bit
- Linux (most anything greater than RHEL 5), 32-bit and 64-bit

# Python versions

- Python 2.7, 3.4-3.7
- NumPy 1.10 and later



# Hardware Support

- x86, x86\_64|AMD64 CPUs
- NVIDIA CUDA GPUs (Compute capability 3.0 and later, CUDA 8.0 and later)
- AMD GPUs (ROCm on Linux)
- ARM 32-bit (Raspberry Pi) and 64-bit (Jetson TX2)
- POWER8|9

# Packaging

- You can depend on Numba to perform the heavy lifting!
- We run CI on most OS/Python/Hardware combinations
- You can ship a single source package
  - PyPi
  - [anaconda.org](https://anaconda.org)
- No need to pre-compile binaries for your users

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# Understood Numba?

- Numba is a
  - just-in-time
  - type-specializing
  - function compiler
  - for accelerating numerically-focused Python

# What is Cooking?

- Dropping Python 2.7 support
- Python → Assembly visualizer
- Automatic inspection of Numpy Support
- Scipy + Numba (aka Scumba)
- Numba-integration-testing (TexasBBQ)
- AirDask-CI

# Getting in Touch

- <https://numba.pydata.org>
- Preferred: GitHub + Gitter
- Stuck? It can't hurt to ask. ;-)