Appendix C: Full Results Tables

For: *Memory Without Storage, Learning Without a Learner* (Neale, 2026)

C.1 Elementary Cellular Automata — Summary by Wolfram Class

All 256 rules analysed. Values are mean ± standard deviation across rules in each class.

Class	n	M	L	D_rate	Characters
1	24	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	static (24)
2	194	0.017 ± 0.028	0.147 ± 0.237	0.101 ± 0.091	mixed (127), static (44), chaotic (19), purposive (3), inert (1)
3	30	0.017 ± 0.013	0.071 ± 0.069	0.181 ± 0.047	mixed (22), chaotic (8)
4	8	0.019 ± 0.010	0.274 ± 0.189	0.137 ± 0.062	mixed (6), purposive (1), chaotic (1)

M is computed using the prediction-based measure from the unified analysis (Section B.3, present-vs-history comparison). For M_pred (model obsolescence) values, see Table C.6.

C.2 Elementary Cellular Automata — Notable Individual Rules

Rule	Class	M	L	D_rate	D_centre	Character	Notes
0	1	0.000	0.000	0.000	0.50	static	All cells die immediately
4	2	0.000	0.000	0.000	0.50	static	Sparse static pattern
18	3	0.016	0.231	0.189	—	mixed	Chaotic with structure
22	3	0.027	0.000	0.178	—	chaotic	No learning, constant surprises
30	3	0.011	0.092	0.146	0.56	mixed	Famous "random number generator"
45	3	0.012	0.000	0.167	—	chaotic	

Rule	Class	M	L	D_rate	D_centre	Character	Notes
54	4	0.039	0.129	0.182	0.55	mixed	Complex localised structures
90	3	0.015	0.087	0.171	—	mixed	XOR rule, fractal pattern
110	4	0.018	0.000	0.146	0.56	mixed	Turing-complete; no L signal
124	4	0.014	0.361	0.175	—	mixed	
131	4	0.009	0.486	0.073	—	purposive	Highest Class 4 L
133	4	0.011	0.482	0.000	—	mixed	High L but no D events
137	4	0.013	0.369	0.167	—	mixed	
184	2	0.000	0.816	0.047	0.48	mixed	Traffic rule; highest L in Class 2
193	4	0.018	0.000	0.178	—	chaotic	No learning signal

Note: Rule 110 (Turing-complete) shows L = 0 because its complexity is sustained rather than convergent — the observer sees no surprise reduction over time. Rule 184 (traffic/majority) shows the highest L among Class 2 rules because it genuinely sorts its density profile, producing a strong early-to-late surprise decrease.

Complete results for all 256 rules are available in the supplementary data file `final_ca.csv`.

C.3 Game of Life — All 18 Patterns

Pattern	Type	M	L	D_rate	D_centre	Character
Block	Still life	0.000	0.000	0.000	0.50	static
Beehive	Still life	0.000	0.000	0.000	0.50	static
Loaf	Still life	0.000	0.000	0.000	0.50	static
Blinker	Oscillator	0.000	0.000	0.000	0.50	static
Toad	Oscillator	0.005	0.000	0.000	0.50	mixed
Beacon	Oscillator	0.001	0.000	0.000	0.50	mixed
Pulsar	Oscillator	0.016	0.000	0.000	0.50	mixed

Pattern	Type	M	L	D_rate	D_centre	Character
Pentadecathlon	Oscillator	0.003	0.028	0.196	0.54	mixed
Glider	Spaceship	0.000	0.233	0.000	0.50	mixed
LWSS	Spaceship	0.000	0.001	0.098	0.50	mixed
MWSS	Spaceship	0.001	0.001	0.098	0.50	mixed
HWSS	Spaceship	0.001	0.001	0.131	0.50	mixed
R-pentomino	**Methuselah**	**0.000**	**0.994**	**0.099**	**0.33**	**purposive**
Acorn	Methuselah	0.000	0.000	0.195	0.56	chaotic
Diehard	Methuselah	0.000	0.000	0.064	0.16	mixed

Summary by type

Type	n	M (mean)	L (mean)	D (mean)
Still life	3	0.000	0.000	0.000
Oscillator	5	0.005	0.006	0.039
Spaceship	4	0.001	0.059	0.082
Methuselah	3	0.000	0.331	0.119

Notes: Blinker, Toad, and Beacon register as "static" because their simple oscillation produces perfectly periodic emissions indistinguishable from constant emissions in terms of prediction performance. Acorn shows L = 0 because 400 steps is insufficient for it to resolve (it requires ~5,200 steps to stabilise). Diehard shows L = 0 because it dies completely by step 130, failing the activity gate.

C.4 Gray-Scott Reaction-Diffusion — All 10 Regimes

Regime	F	k	M	L	D_rate	D_centre	Character
Uniform death	0.078	0.061	0.000	0.000	0.000	0.50	static
Stable spots	0.035	0.065	0.000	0.107	0.217	0.57	mixed

Regime	F	k	M	L	D_rate	D_centre	Character
Labyrinthine stripes	0.040	0.065	0.000	0.311	0.221	0.51	mixed
Moving spots	0.014	0.054	0.000	0.000	0.126	0.40	mixed
Mitosis	**0.028**	**0.062**	**0.000**	**0.912**	**0.198**	**0.47**	**mixed**
Pulsing	0.025	0.060	0.000	0.000	0.200	0.47	chaotic
Coral growth	**0.062**	**0.061**	**0.000**	**0.917**	**0.177**	**0.54**	**mixed**
Spatiotemporal chaos	0.026	0.051	0.000	0.000	0.080	0.22	mixed
Worm-like meandering	0.054	0.063	0.000	0.192	0.141	0.52	mixed
Sparse spots	**0.030**	**0.062**	**0.000**	**0.954**	**0.213**	**0.48**	**mixed**

Note: M from the unified prediction measure (present-vs-history) is zero throughout because the rolling mean predictor tracks the smooth Gray-Scott dynamics adequately from the present state alone. The model obsolescence measure M_pred (Table C.6) captures the regime shift that the unified M misses. See Section 4.5 and Appendix B.3.

C.5 Sorting Algorithms — All 6 Variants

Variant	Category	Steps	M	L	D_rate	D_centre	Character
Already sorted	Control	20	0.000	0.000	0.000	0.50	static
Bubble sort	**Top-down**	**28**	**0.000**	**0.689**	**0.200**	**0.61**	**mixed**
Self-sorting bubble	Bottom-up	20	0.000	0.000	0.286	0.60	chaotic
Self-sort with defects	Defective	6	0.000	0.000	0.000	0.50	static
Selection sort	**Top-down**	**31**	**0.000**	**0.408**	**0.143**	**0.72**	**mixed**
Reverse bubble	**Worst case**	**31**	**0.000**	**0.420**	**0.048**	**0.97**	**mixed**

Notes: Self-sorting bubble shows L = 0 because the random visit order makes late-phase emissions *more* surprising than early-phase, even though the array becomes more sorted. The observer's surprise increases because the random ordering prevents the observer from predicting which elements will swap next. Self-sort with defects ran for only 6 steps (insufficient for analysis) due to the small array size (n=30); a larger array would produce a richer emission stream.

C.6 M_pred (Model Obsolescence) — Cross-Substrate Comparison

These values are from the dual-memory comparison (Section 4.5), which tests M using the model obsolescence measure: error(early model on late data) − error(late model on late data). This measure discriminates across substrates where the unified prediction-based M (present-vs-history) does not.

System	Substrate	M_pred	M_cohen	L	D_rate
Sort: reverse bubble	Sorting	0.364	4.203	0.420	0.050
GS stripes	Gray-Scott	0.325	8.188	0.311	0.186
GS chaos	Gray-Scott	0.321	2.364	0.000	0.094
GS mitosis	Gray-Scott	0.253	5.042	0.912	0.200
GS coral	Gray-Scott	0.193	3.951	0.917	0.190
GS pulsing	Gray-Scott	0.175	2.822	0.000	0.198
Sort: selection	Sorting	0.168	2.885	0.408	0.050
GS spots	Gray-Scott	0.150	4.255	0.107	0.190
GoL Diehard	GoL	0.095	3.003	0.000	0.067
CA 184	CA	0.027	0.326	0.816	0.014
GoL R-pentomino	GoL	0.015	0.371	0.994	0.100
GoL Glider	GoL	0.002	0.033	0.233	0.010
CA 110	CA	0.001	0.095	0.000	0.190
CA 54	CA	0.000	0.101	0.129	0.201
CA 30	CA	0.000	0.125	0.092	0.180
GS death	Gray-Scott	0.000	0.117	0.000	0.000
Sort: bubble	Sorting	0.000	3.876	0.689	0.177
GoL Block	GoL	0.000	0.000	0.000	0.000
GoL Blinker	GoL	0.000	0.000	0.000	0.000
Sort: already sorted	Sorting	0.000	0.000	0.000	0.000

Spearman rank correlation between M_pred and M_cohen: $\rho = 0.75$, $p < 0.0001$.

C.7 M∩L∩D Overlap — Cross-Substrate Top Systems

Using M_pred (model obsolescence) for the memory component. Overlap = (M_pred × L × D_rate)^(1/3), computed only where all three are positive.

Rank	System	Substrate	M_pred	L	D_rate	Overlap
1	GS mitosis	Gray-Scott	0.253	0.912	0.200	0.359
2	GS coral	Gray-Scott	0.193	0.917	0.190	0.323
3	GS stripes	Gray-Scott	0.325	0.311	0.186	0.266
4	Sort: reverse bubble	Sorting	0.364	0.420	0.050	0.197
5	Sort: selection	Sorting	0.168	0.408	0.050	0.151
6	GS spots	Gray-Scott	0.150	0.107	0.190	0.145
7	GoL R-pentomino	GoL	0.015	0.994	0.100	0.113
8	CA 184	CA	0.027	0.816	0.014	0.067

Systems from all four substrates appear in the top 8. The overlap identifies pattern-forming reaction-diffusion regimes, convergent sorting processes, a GoL methuselah, and a CA traffic rule — systems that human researchers independently classify as "interesting" or "complex" — despite these systems sharing no physics, mathematics, or structural features.

C.8 Habituation Frequency Sweep — Gray-Scott Response Profiles

System: Gray-Scott stable spots (F=0.035, k=0.065). Tap strength: ΔV=+0.15, ΔU=−0.15, radius=3. Relaxation: 50 steps. Values normalised to first-tap response.

Tap	Int=30	Int=50	Int=80	Int=120	Int=200	Int=400	Int=800
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	0.658	0.387	0.360	0.487	0.489	0.433	0.579
3	0.284	0.054	0.280	0.421	0.491	0.529	1.049
4	0.068	0.035	0.274	0.398	0.500	0.657	1.365
5	0.021	0.085	0.249	0.395	0.567	0.953	0.668
6	0.007	0.085	0.246	0.396	0.851	0.749	0.624
7	0.044	0.059	0.248	0.427	0.629	1.460	0.634
8	0.068	0.046	0.249	0.513	0.665	0.906	0.501
9	0.073	0.049	0.262	0.706	0.742	0.699	0.382
10	0.063	0.054	0.289	0.832	0.599	0.556	0.374
11	0.049	0.055	0.338	0.534	0.711	0.849	0.368
12	0.038	0.055	0.433	0.662	0.946	0.599	0.365

Interval	Max decline	Observer's inference
30	99%	Strong habituation + spontaneous recovery
50	93%	Sustained habituation
80	75%	Habituation + partial recovery
120	60%	Habituation + recovery
200	26% (then increase)	Sensitisation
400	19%	No consistent learning
800	43%	Gradual decline (ambiguous)

C.9 Multi-Observer Feature Investigation — L by Individual Feature

For each system, L is computed using each emission feature alone, showing which features carry the learning signal and which add noise (dilute). Best single feature highlighted.

Bubble Sort (5 features)

Feature	L (single)	vs L(full) = 0.689
Inversions	**0.914**	Above full — best single channel
Displacement	0.865	Above full
Block entropy	0.864	Above full
Activity	0.698	Above full
Sortedness	0.571	Below full

GS Mitosis (6 features)

Feature	L (single)	vs L(full) = 0.912
Var_V	**0.970**	Above full — best single channel
Mean_V	0.954	Above full
Mean_U	0.952	Above full
Activity	0.929	Above full
Gradient energy	0.918	Above full
Entropy	0.910	Approximately equal

CA Rule 30 (4 features)

Feature	L (single)	vs L(full) = 0.092
Spatial entropy	**0.264**	Above full — best single channel
Boundaries	0.085	Below full
Activity	0.059	Below full
Density	0.000	No learning signal

CA Rule 54 (4 features)

Feature	L (single)	vs L(full) = 0.129
Density	**0.214**	Above full — best single channel
Activity	0.211	Above full
Spatial entropy	0.034	Below full
Boundaries	0.000	No learning signal

GoL R-pentomino (4 features)

Feature	L (single)	vs L(full) = 0.994
Spatial entropy	**0.994**	Equal to full — carries entire signal
Density	0.000	Activity gate fails (system static in this channel)
Boundary density	0.000	Activity gate fails
Activity	0.000	Activity gate fails

Universal finding: For all five systems tested, adding features to the best single channel never increases L — it can only dilute. The best single feature produces L ⩾ L(full) in every case.

C.10 Data Availability

Complete results for all 287 systems are available as CSV files:

- `final_ca.csv` — 256 elementary CA rules (M, L, D, character, Wolfram class)
- `final_gol.csv` — 18 Game of Life patterns
- `final_gs.csv` — 10 Gray-Scott regimes
- `final_sort.csv` — 6 sorting algorithm variants
- `mld_dual_memory.py` — Script producing M_pred and M_cohen comparisons

All scripts and data available at goleudy.ai. All simulations are reproducible from the published code with the random seeds specified in Appendix A.