Program Description I

Program Title: THE GAME OF LIFE

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Program Description, Equations, Variables: The game of LIFE created by John Horton Conway is a pattern generation game played in open 2-D space. Specific initial configurations — cellular automata — in a Cartesian framework evolve into new patterns through successive generations.

The basic transformation rules from one generation to the next — ($G^n \to G^{n+1}$) — are readily stated. Any cell alive in G^n remains alive in G^{n+1} if it has either 2 or 3 live neighbors in G^n (of the 8 surrounding cells). Otherwise it dies of "isolation" (0 or 1 live neighbor) or "overpopulation" (4-8 live neighbors). Any cell dead (empty) in G^n becomes live in G^{n+1} if and only if it has exactly 3 live neighbors in G^n. Consider each G as instantaneously created.

The program implements LIFE in a 10x10 100-cell universe. This grid size is sufficient to demonstrate many of the beautiful and striking life patterns that may evolve. Some configurations evolve thru hundreds of generations, some peter out rapidly, some reach stable ("still life") or oscillatory states, and some endure indefinitely periodically bearing "off-spring" (eg. glider guns releasing gliders). Some patterns engulf, destroy or transmute others on collision.

~~Operating Limits and Warnings~~

n = No. of evolved generations from initial G^0 to G^n

k = cell label as noted on grid ($0 \le k \le 99$)

c_k = column of cell k (modulo 10)

ℓ_i = row or line i ($0 \le i \le 9$)

Σ_k = No. of live cells around k = sum of their contents

I_k^n = contents of k in n^{th} generation: 1 = live 0 = dead

G^n = current generation

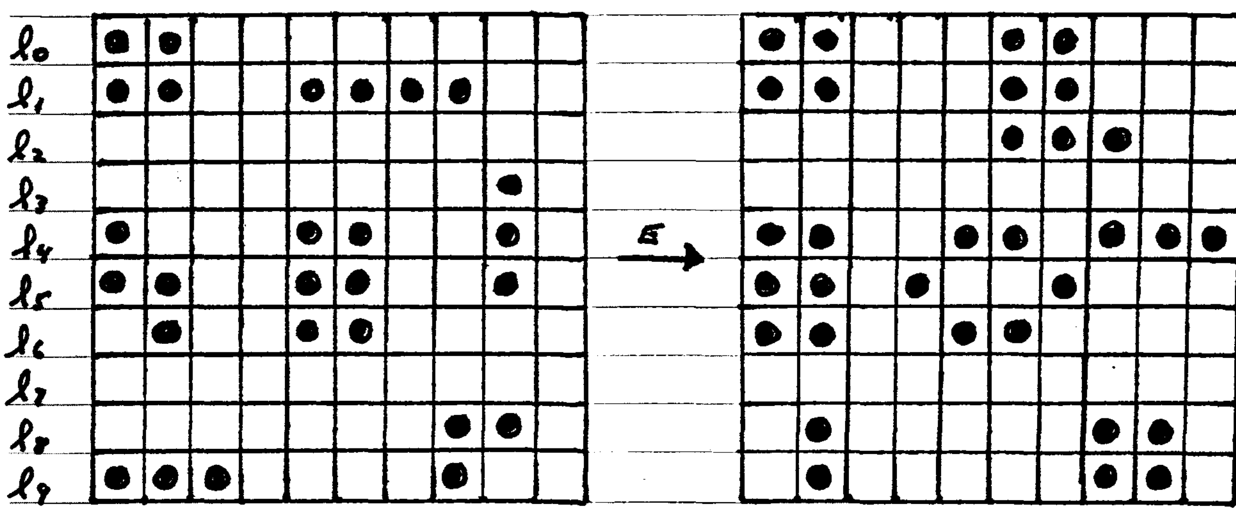
	c_0	c_1	c_2	...	c_9
ℓ_0	0	1	2	...	
ℓ_1	10	11	12	...	
ℓ_2	20	21	22	...	
⋮	⋮	⋮	⋮	⋱	
ℓ_9					

LIFE

Program Description II

Sketch(es) For sample problem below, leave program in manual mode [f e → 0], press A to clear (unnecessary for first G^0), and then enter G^0 line by line [1.1 B, 1.1001111 B, 0 B, 0.00000001 B, ··· 0.00000011 B, 1.1100001 B]. Terminal zeros may be omitted. DSP 9 notation preserves leading zeros. Press C to review accuracy of G^0 entry. Now press E. Each ½ min. the next cell k (from 0 to 99) will be displayed with its next-generation contents (1 = live 0 = dead). At completion (50 min.), G^{n+1} is displayed line by line.

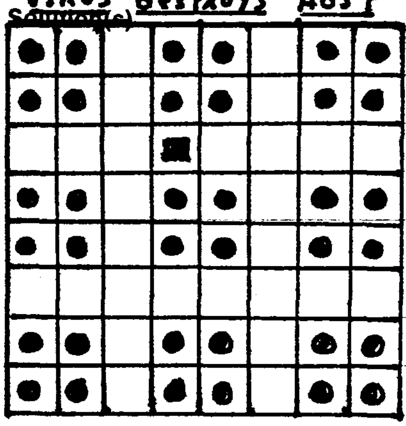
Sample Problem(s) G^0 G^1



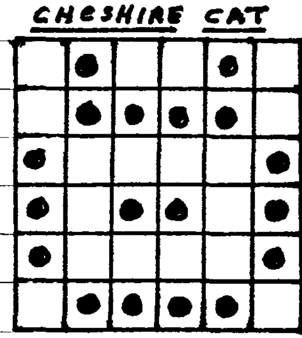
Left-center tetromino → "Beehive" in 2 generations.

Center pattern is the "beehive", a stable "still life".

VIRUS destroys HOST

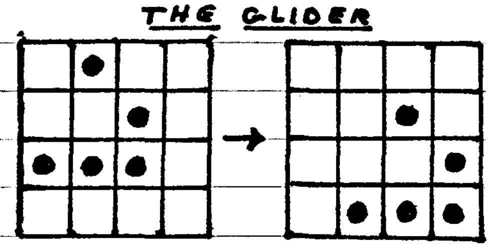


CHESHIRE CAT



→ GRIN in G^6
→ pawprint in G^7

THE GLIDER



After 4 generations the glider has moved one unit diagonally.

Reference(s) ① MARTIN GARDNER, Mathematical Games, Scientific American: esp. Oct. 1970 (1st introduced) + Feb. 1971 (many startling new patterns including the three above, + discussion of cellular automata).

② CARL HELMERS, BYTE, Sept. + Oct. 1975 (1st two issues): extensive discussion of computer implementation of LIFE.

User Instructions

LIFE 10×10

◀1 AUTO ? 2▶

clear | load | review | | GO→ G^{n+1}

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS		OUTPUT DATA/UNITS
①	Load program from both sides of card.				
②	Select AUTO or MANUAL mode.		f	e	1 or 0
	AUTO mode : output = 1 } alternate presses				
	MANUAL mode : output = 0 }				
	Auto mode permits unattended HP-97				
	printout of successive generations.				
	Manual mode → halt after each new generat.				
③	Initial all parameters and generations to 0.		A		
④	Enter initial generation G^0 line by line.	l_0	B		1 } next line prompt
	$l_i = d_0 . d_1 d_2 d_3 d_4 d_5 d_6 d_7 d_8 d_9$	l_1	B		2
	e.g., $l_0 = 1.001000010$ if cells 0, 3, 8	l_2	B		3
	of top row are alive. This format will	⋮	⋮		⋮
	preserve + display all leading zeros.	l_9	B		10 All Entered
④′	Alternate G^0 entry of all 10 lines $(0 \le i \le 9)$	l_i	STO	R_i	
⑤	Review G^0 for correct entry.		C		G^0, 0
	If error, correct by ④′ (or ③ then ④)				
	Each line label and line is displayed sequentially				
	in 1-sec. and 5-sec. pause modes respectively:				
	$(0, l_0, 1, l_1, \cdots 9, l_9)$. Then the generation				
	number (0) is shown. Do not omit ⑤ if HP-97				
	printout of $(G^0, 0)$ is desired.				
⑥	Obtain successive life generations.		E		G^1
	Press once only if auto mode was selected. Cell		E		G^2
	no. and contents of successive cells from 0-99 will		E		G^3
	be 1-sec. pause-displayed every ½ min: eg. (3.1) =		⋮		⋮
	cell 3 alive; (65.0) = cell 65 dead in G^{n+1}. Full G^{n+1}				
	evolves in 50 min. + is then displayed line by line as				
	in ⑤. See (n+1) when program stops (manual mode).				
	In both modes, HP-97 prints, formats + labels each genera.				
⑦	May review G^{n+1} + (n+1) after each generat. (manual)		C		G^{n+1}, n+1
⑧	For a new initial configuration G^0, go to ③				

Program Listing I

STEP	KEY ENTRY	KEY CODE	COMMENTS
001	g LBL e	32 25 15	Continuous generation mode: F_0 set 1 in R_x
002	DSP 0	23 00	
003	h F? 0	35 71 00	
004	GTO 1	22 01	
005	h SF 0	35 51 00	
006	1	01	
007	h RTN	35 22	
008	f LBL 1	31 25 01	Single $G^n \to G^{n+1}$: F_0 reset 0 in R_x
009	h CF 0	35 61 00	
010	0	00	
011	h RTN	35 22	
012	f LBL A	31 25 11	Initial: clear all storage registers
013	f CL.REG	31 43	
014	f P⇄S	31 42	
015	f CL.REG	31 43	
016	h RTN	35 22	
017	f LBL B	31 25 12	After each line ℓ_i is stored, next i (i.e., i+1) is displayed as a prompt.
018	STO (i)	33 24	
019	f ISZ	31 34	
020	h RC I	35 34	
021	DSP 0	23 00	
022	h RTN	35 22	
023	f LBL C	31 25 13	The generation in $R_0 - R_9$ (initially G^0, then each subsequent G^i) is outputted in 5-sec. display mode, labelled (generation n), and (for HP-97 printout), formatted.
024	0	00	
025	h ST I	35 33	
026	f LBL 0	31 25 00	
027	h RC I	35 34	
028	DSP 0	23 00	
029	h PAUSE	35 72	
030	RCL (i)	34 24	
031	DSP 9	23 09	
032	f -x-	31 84	
033	f ISZ	31 34	
034	9	09	
035	h RC I	35 34	
036	g x≤y	32 71	
037	GTO 0	22 00	
038	0	00	
039	h ST I	35 33	
040	RCL E	34 15	
041	DSP 0	23 00	
042	h SPACE	35 84	
043	f -x-	31 84	
044	h SPACE	35 84	
045	h SPACE	35 84	
046	h RTN	35 22	
047	f LBL E	31 25 15	Start evolution of new generation $G^n \to G^{n+1}$ (k in R_A) → (c_k in R_B)
048	RCL A	34 11	
049	.	83	
050	1	01	
051	×	71	
052	g FRACT	32 83	
053	1	01	
054	0	00	
055	×	71	
056	STO B	33 12	

STEP	KEY ENTRY	KEY CODE	COMMENTS
057	RCL A	34 11	F_1 on if g_k^n is alive
058	f a	32 22 11	
059	1	01	
060	g x=y	32 51	
061	h SF 1	35 51 01	
062	RCL A	34 11	obtain $\Delta\Sigma_k$ from the column-independent cells: (k+10) (k−10)
063	1	01	
064	0	00	
065	+	61	
066	f b	32 22 12	
067	RCL A	34 11	
068	1	01	
069	0	00	
070	−	51	
071	f b	32 22 12	
072	RCL B	34 12	obtain the $\Delta\Sigma_k$ contribution from surrounding cells (k−1) (k−11) (k+9) unless k is a 1st-column cell: ($c_k = 0$).
073	f x=0	31 51	
074	GTO 2	22 02	
075	RCL A	34 11	
076	1	01	
077	−	51	
078	f b	32 22 12	
079	RCL A	34 11	
080	1	01	
081	1	01	
082	−	51	
083	f b	32 22 12	
084	RCL A	34 11	
085	9	09	
086	+	61	
087	f b	32 22 12	
088	f LBL 2	31 25 02	obtain $\Delta\Sigma_k$ contribution from surrounding cells (k+1) (k+11) (k−9) unless k is a last-column cell: ($c_k = 9$)
089	RCL B	34 12	
090	9	09	
091	g x=y	32 51	
092	GTO 3	22 03	
093	RCL A	34 11	
094	1	01	
095	+	61	
096	f b	32 22 12	
097	RCL A	34 11	
098	1	01	
099	1	01	
100	+	61	
101	f b	32 22 12	
102	RCL A	34 11	
103	9	09	
104	−	51	
105	f b	32 22 12	
106	f LBL 3	31 25 03	F_2 on if g_k^{n+1} is alive i.e., either $\Sigma_k = 3$ or ...
107	3	03	
108	RCL C	34 13	
109	g x=y	32 51	
110	h SF 2	35 51 02	
111	2	02	
112	g x≠y	32 61	

REGISTERS

0	1	2	3	4	5	6	7	8	9
ℓ_0	ℓ_1	ℓ_2	ℓ_3	ℓ_4	ℓ_5	ℓ_6	ℓ_7	ℓ_8	ℓ_9 G^n

S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
ℓ_0	ℓ_1	ℓ_2	ℓ_3	ℓ_4	ℓ_5	ℓ_6	ℓ_7	ℓ_8	ℓ_9 G^{n+1}

A	B	C	D	E	I
k = current cell	c_k = current column	Σ_k = no. live cells around k	g_k^{n+1} = 2_k^n transform	n = current generat.	multiple

STEP	KEY ENTRY	KEY CODE	COMMENTS
	GTO 4	22 04	... $\Sigma_k = 2$ with g_k^n alive
	h F? 1	35 71 01	
	h SF 2	35 51 02	
	f LBL 4	31 25 04	g_k^{n+1} into R_D =1 if alive =0 if dead
	h CF 1	35 61 01	
	0	00	
	h F? 2	35 71 02	
120	1	01	
	STO D	33 14	
	f P⇄S	31 42	obtain $d_1 d_2 \cdots g_k^{n+1} . d d \cdots$ into Rx from evolving G^{n+1}, after a primary-secondary interchange. This g_k^{n+1} is a 'dummy' value.
	RCL A	34 11	
	•	83	
	1	01	
	×	71	
	ENTER↑	41	
	f INT	31 83	
	h STI	35 33	
130	−	51	
	1	01	
	0	00	
	×	71	
	g 10^x	32 53	
	RCL (i)	34 24	
	×	71	
	ENTER↑	41	'g_k^{n+1}' is then isolated and extracted from ℓ_k of G^{n+1}, and replaced by the true g_k^{n+1} from R_D. G^n and G^{n+1} are then repositioned.
	g FRAC	32 83	
	−	51	
140	h LST x	35 82	
	h x⇄y	35 52	
	•	83	
	1	01	
	×	71	
	f INT	31 83	
	1	01	
	0	00	
	×	71	
	RCL D	34 14	
150	+	61	
	+	61	
	RCL B	34 12	
	CHS	42	
	g 10^x	32 53	
	×	71	
	STO (i)	33 24	
	f P⇄S	31 42	
	RCL A	34 11	Each k and g_k^{n+1} are pause-displayed in DSP 1 mode as k.g_k^{n+1}
	RCL D	34 14	
160	•	83	
	1	01	
	×	71	
	+	61	
	DSP 1	23 01	
	h PAUSE	35 72	
	0	00	Prepare to transform next cell ...
	STO C	33 13	
	9	09	

STEP	KEY ENTRY	KEY CODE	COMMENTS
	9	09	... if next k is still in range ($0 \le k \le 99$). 1st reset $\Sigma_k=0$
170	RCL A	34 11	
	1	01	
	+	61	
	STO A	33 11	
	g x≤y	32 71	
	GTO E	22 15	
	RCL E	34 15	If all 100 cells have been transformed, increment generation counter, reset k=0, put new G into R_0-R_9, display, and halt. (unless in auto mode)
	1	01	
	+	61	
	STO E	33 15	
180	0	00	
	STO A	33 11	
	f P⇄S	31 42	
	C	31 22 13	
	h F? 0	35 71 00	
	GTO E	22 15	
	h RTN	35 22	
	g LBL a	32 25 11	For any cell label k in Rx, extract g_k^n, the contents of cell k, from G^n, and leave g_k^n in Rx
	•	83	
	1	01	
190	×	71	
	ENTER↑	41	
	f INT	31 83	
	h STI	35 33	
	−	51	
	1	01	
	0	00	
	×	71	
	g 10^x	32 53	
	RCL (i)	34 24	
200	×	71	NOTE: Program subroutining has been minimized to reduce execution time.
	f INT	31 83	
	•	83	
	1	01	
	×	71	
	g FRAC	32 83	
	1	01	
	0	00	
	×	71	
	h RTN	35 22	
210	g LBL b	32 25 12	For any of the 8 cells surrounding cell k and within 0-99 bounds: obtain its contribution $\Delta\Sigma_k$ to the sum Σ_k of the cell contents of all 8 cells. Σ_k = no. of live cells around k.
	f x<0	31 71	
	h SF 2	35 51 02	
	9	09	
	9	09	
	h x⇄y	35 52	
	g x>y	32 81	
	h SF 2	35 51 02	
	h F? 2	35 71 02	
	h RTN	35 22	
220	f a	32 22 11	
	RCL C	34 13	
	+	61	
	STO C	33 13	
	h RTN	35 22	

LABELS

A clear	B load	C review	D	E GO → G^{n+1}
a $k \to g_k^n$	b → $\Delta\Sigma_k$	c	d	e AUTO ?
0 READOUT LOOP	1 AUTO	2 for $\Delta\Sigma_k$	3 → g_k^{n+1}	4 $g_k^{n+1} \to R_D$
5	6	7	8	9

FLAGS

0	AUTO if ON
1	g_k^n alive if ON
2	multiple
3	

SET STATUS

FLAGS	ON	OFF	TRIG		DISP	
0	☐	☑	DEG	☑	FIX	☑
1	☐	☑	GRAD	☐	SCI	☐
2	☐	☑	RAD	☐	ENG	☐
3	☐	☑			n 2	