EMERGY AND EVOLUTION

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Hierarchies of biological systematics have long been related to the evolutionary process. Automated computation of similarities are explained with hypotheses about phylogeny and evolutionary trees. In this presentation, we relate the hierarchies of evolution and biological systematics to energy transformations.

A simulation model of the process of evolution is used to relate energy to the information of systematics. According to the definition of EMERGY, spelled with an "M", solar EMERGY of the products of evolution is the solar energy required for their development, in units of solar emjoules. Since individuals similar enough to be classified together are inferred to share common information, taxonomic units were used as categories of shared genetic information. The times required for the simulation model to develop genera, families, orders, classes, and phyla suggest the solar EMERGY of each category. A model of species evolution calibrated for the Galapagos Islands was previously published (Odum, 1988b). The new simulation model uses the accumulations of microevolutionary change to innovate higher categories followed by extinctions from macroevolutionary displacement.

The microcomputer model EVOLSYST is given in ordinary BASIC. The new program EXTEND was also used for simulating energy language diagrams. The main symbols of energy language have been defined as blocks so that connecting them on Macintosh computer joins the equations of each block to form a simulation program without the need to consider mathematics directly.

Transformity and Hierarchy

As summarized recently (Odum, 1988a, 1988b), we have been developing the link between energy and hierarchy, recognizing that the energy dispersal inherent in useful transformations measures position in natural hierarchies that result from self organization. We have long recognized that energy at one level in a hierarchy should not be regarded as the work equivalent of energy at another level. The position in energy hierarchy is given by the EMERGY of one type per unit energy of another kind, which was named the Transformity. Of all the items in the biosphere, solar transformities are highest for items of shared information. Much time and energy is required for their development. In this paper we consider the solar transformity of some of the products of evolution. Although the example used is biological evolution of the categories of systematics, the model is more general and may be used for other kinds of information evolution.

In all fields we have examined, there are already hierarchical energy diagrams, power spectra, and the like where specialists in these fields have recorded the amounts of energy at one level that support lesser amounts at a higher hierarchical level. There are food web diagrams, meteorological energy diagrams, geochemical distribution diagrams, molecular energy distributions, the energy web of the bioshpere, etc. In all these, size and turnover time are correlated, which is another hierarchical property, one that can be used to verify the numbers used to represent hierarchies. Many transformities can be calculated from these well established energy distributions worked out carefully by the people in these fields.

In other words, a transformity is as good as the network diagram and evaluation in representing the observed natural hierarchies of the real world. Tables of transformities are really tables of observed energy hierarchy. Because of the way we are educated as specialists, it isn't easy for any one person to find the best hierarchical data in each field. Hierarchies in weather may not be known to those who know about hierarchies in social organization; hierarchies in the brain may not be known to those studying hierarchies in geological transformation, etc. Ultimately, those in each field need to provide the transformities from that field. The task of generalists is to make enough preliminary calculations to suggest the opportunity and need. The rough orders of magnitude used to calibrate the demonstration simulations in this paper need to be replaced with the best data on speciation rates and numbers of categories.

Information Categories

In some previous applications of EMERGY theory (Odum, 1988a, 1988b), means for evaluating transformities of information were suggested. Several categories of information were defined.

> Information of a copy---small EMERGY value added in making one copy.
>
> Information isolated from an operating system has higher transformity than the system it operates.
>
> Information of many distributed copies becomes shared information with large territory, turnover time, and transformity.
>
> Information of the first or last copy has EMERGY value added according to the transformation necessary from the nearest available precursor.
>
> Information in bits may be multiplied by transformity to obtain embits so that bits at one level of hierarchy may be compared with that at another.
>
> Biological information of inheritance has solar transformities which can be calculated from the territory required for support.

Microscopic and Macroscopic Evolution

The fossil record has evidence for microevolution of species and infrequent rapid, saltatory, macroscopic evolution of larger categories. These are not really contradictory, since many small changes accumulating with the mechanisms of speciation (mutation, isolation, recombination, drift, etc.) provide new assortments of precursors to larger change. When enough of the ingredients of new structure and function have accumulated, it is possible for recombination to generate something radically new that is a macroscopic jump in utility of performance, capable of displacing much of what went before.

We observed this in our technological evolution, when a long period of accumulation of small innovations finally generated the combination that allowed the microcomputer to appear. It was so useful that it soon displaced many older ways of operating. Using terminology of biological evolution, the microcomputer is now in "rapid adaptive radiation". The appearance of the microcomputer in the fossil record will show the same kind of world-wide displacement that a future archaeologist might blame on astronomic events.

Evolution of categories may be like a counting circuit (once common on radioactive counting equipment). For example, accumulation of 10 counts trips one count at the next level of hierarchy, turning on the light for that level; accumulation of 10 counts at this second level turns on the light for the next level and so on.

Simulation Model

Energy systems language was used to diagram the evolutionary process as shown in Figure 1. Also given with Figure 1 are the equations for the simulations that follow automatically from energy systems diagramming. All systems are apparently hierarchical as a result of energy transformations. With energy systems diagramming, by convention, items are placed from left to right in order of their solar transformity. The diagram shows the energy sources of the biosphere on the left driving the production of living individuals. In proportion to this flux microevolutionary innovations develop that collectively constitute new species. In turn, species generate the information that innovates genera, genera causing families, etc. In the model each unit of a higher category that was developed was accompanied by extinction and replacement of the members of the lower level from whose microevolutionary accumulations the new emergent property of shared useful information developed.

The flows of energy at each level generate systematic categories at the next. The model has a pattern of nested hierarchical autocatalytic pathways. Hierarchical webs of autocatalytic units is a systems design that is self organizing for maximum power (and maximum EMPOWER). As the number of units in each systematic category develops, a greater fraction of the available input energy is incorporated into the system and fed back into use, where use is defined as autocatalytic reinforcement. Also given with Figure 1 are the equations for the simulations that follow automatically from energy systems diagramming.

Calibration

For calibration, storages and flows were used from Table 1, which has steady state rates of generation and extinction of units. A spread sheet template (Lotus) was set up to calculate the coefficients from these flows and storages. Input energy I was given a normalized value of 1. For the Earth as a whole, I is 8.1 E24 solar emjoules per year. The base rate of

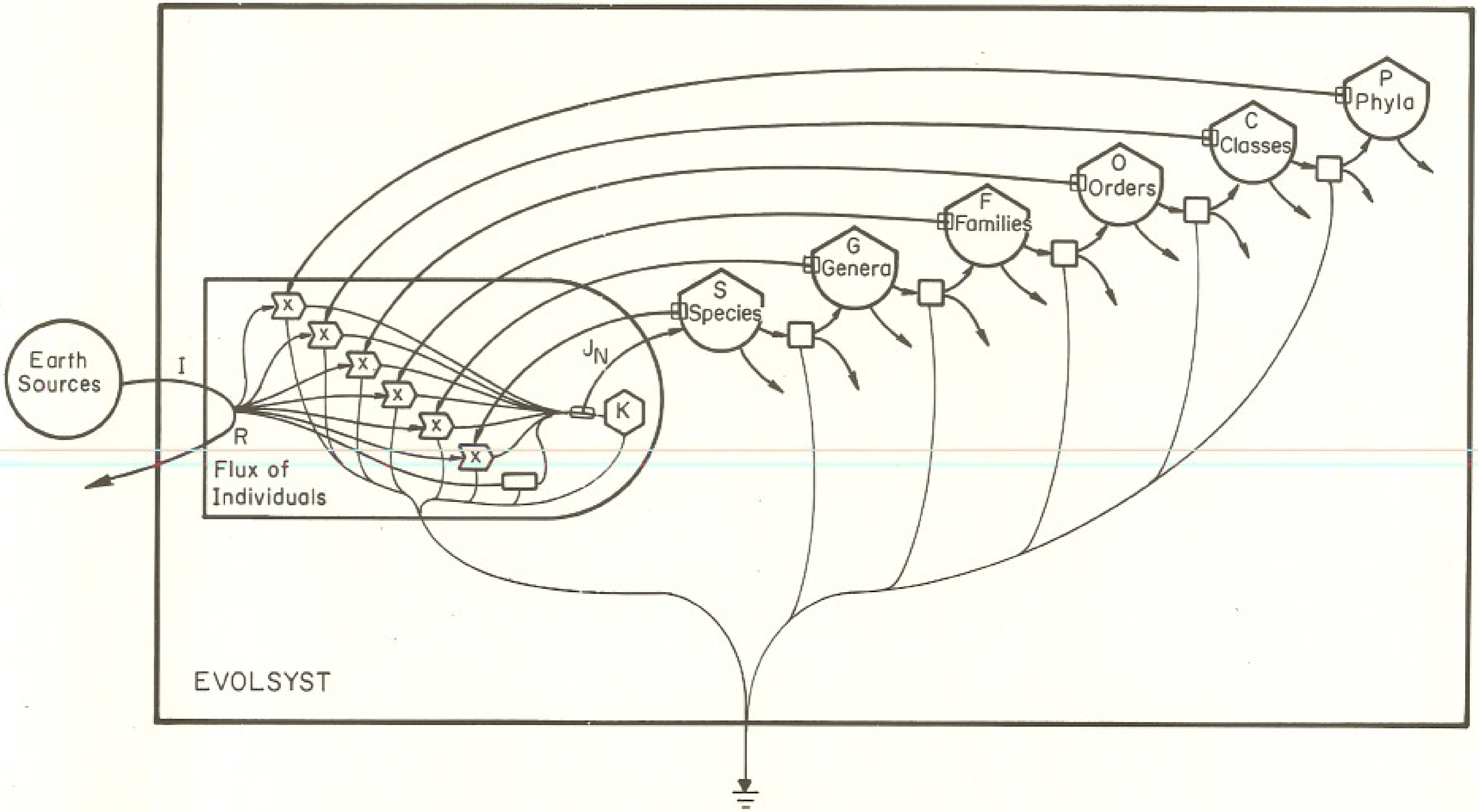

Figure 1. Energy systems model of evolution of the shared information categories recognized in taxonomic classification. Equations:

R = I/(1 + K0 + K1*S + K2*G + K3*F + K4*O + K5*C + K6*P)

JN = [K7*R + K8*R*S + K9*R*G + K10*R*F + K11*R*O + K12*R*C + K13*R*P]

DS = K14*JN - K15*S - K16*S

DG = K17*S - K19*G - K20*G

DF = K22*G - K23*F - K24*F

DO = K26*F - K27*O - K28*O

DC = K30*O - K31*C - K32*C

DP = K34*C - K35*P

production used 30% of this with 10% added for each systematic category developed to the calibration level.

Hierarchical Diagram of Systematic Quantities

The output of the simulation is the systematics distribution in Figure 2. The result is typical of the number of species, genera, families, orders, etc. like that found in today's real biosphere. This figure was generated by the simulation model of evolution in Figure 2. Like hierarchical diagrams in many other fields, this one suggests that many species are required to support a genus, many genera to support a family, etc.

Including tide, the average EMERGY flux of Earth inputs was estimated as about 8.1 E24 solar emjoules per year (Odum, 1988). This was used as the source input and divided by the number of units produced per year (Table 1) to get solar EMERGY per category (individual based solar transformity). See horizontal axis of Figure 1.

Where an energy systems model is of a network that has been in existence for a long time, we may assume that self organization has developed the best efficiencies compatible with maximum contributions to the larger web's performance under environmental and/or economic competition. When numerically evaluated according to observations, these diagrams may represent the best possible energy transformation efficiencies consistent with maximum power. Efficiency can be increased by adding load and reducing power, but the self organization process only reinforces a network that generates useful products at maximum rate, where use means to feed back and amplify lower levels in the hierarchy.

Table 1
Quantities used for Calibrating EVOLSYST in Figure 1

Unit	Flux/year	Storage	Turnover, years
Individuals	5 E16	--	1
Species	5 E2	5 E6	1E4
Genera	5	5 E5	1E5
Families	5 E-2	5 E4	1E6
Orders	5 E-4	5 E3	1E7
Classes	5 E-6	5 E2	1E8
Phyla	5 E-8	5 E1	1E9

If the simulation is started with only a few initial species, the number of species increases first. In proportion to the number of individuals processed, higher information levels develop accompanied by substitution of new species for the old ones. A new systematic category represents a broadened level of shared information, larger territory, longer time constant, and higher transformity. The development of higher shared information levels feeds back to augment the system productivity, reinforcing the development of maximum empower. Each iteration time step is 100,000 years. The full complement of phyla and lesser hierarchical categories is developed after a billion years. The graph in Figure 2 resulted after 2 million years. Note that the two highest level categories have not developed much yet. The model helps understand the relationship of energy processing and development of shared information. The BASIC simulation program is Table 2.

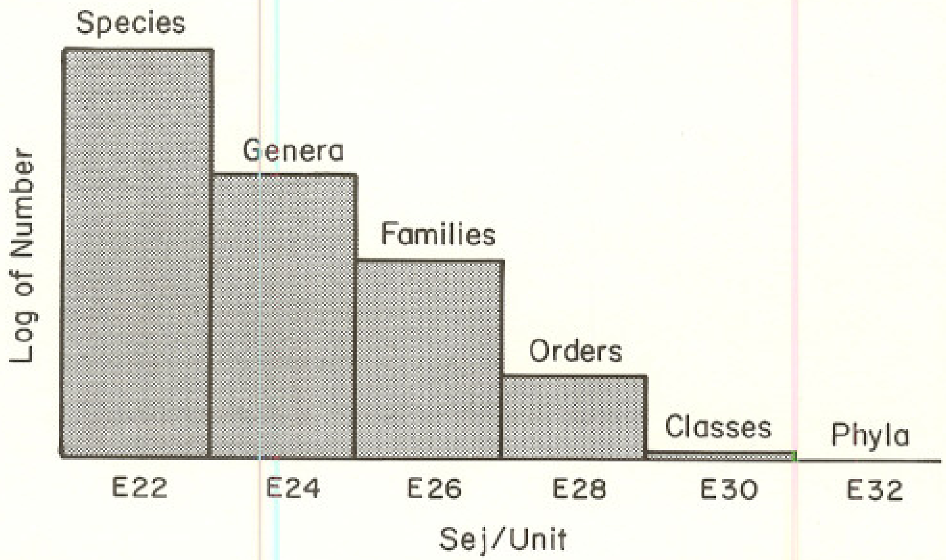

Figure 2. Hierarchy of systematic categories generated by the energy systems model of evolution in Figure 1 and its simulation program in Table 2.

Using Energy Systems Language with EXTEND

Like the older program Stella, EXTEND allows symbols to be connected with a mouse, causing the equations to be set up automatically to simulate system performance. EXTEND allows the user to make his own symbols and write the program for each. In collaboration with Elisabeth C. Odum and Dr. Nils Petersen of University of Oregon at Eugene, we have done this with the Energy Language Symbols. Figure 3 is the print-out of the MacIntosh screen with the symbols connected to simulate one step in shared information development. The systematics evolution model diagrammed in Figure 1 has 6 steps. The library of symbols, some of which are represented in Figure 3, can be supplied by us to those who have purchased the EXTEND program. EXTEND is obtained from:

Imagine That, Inc.
7109 Via Carmela,
San Jose, California, 95139

References Cited

Odum, H.T. 1988a. Self-organization, Transformity, and Information. Science 242:1132-1139.

Odum, H.T. 1988b. Living with Complexity. Crafoord Prize Lectures for 1987. pp. 19-85. Royal Swedish Academy of Sciences, Stockholm.

Table 2

BASIC Simulation Program EVOLSYST for IBM Compatible PC

```
3 REM EVOLSYST (Simulation of the evolution of Systematic Categories)
5 REM For time graphs, set X = 0; for bar graphs, set X = 1:
6 X=1
7 CLS
8 REM GRAPHICS:
9 SCREEN 1,0
11 COLOR 0,1
12 LINE (50,180)-(230,180),3
13 IF X = 1 GOTO 40
15 LINE (0,0)-(319,180),3,B
18 LINE (0,30)-(320,30),3
20 LINE (0,60)-(320,60),3
25 LINE (0,90)-(320,90),3
27 LINE (0,120)-(320,120),3
30 LINE (0,150)-(320,150),3
40 REM Scaling factors
60 DT = 10000!
62 TO = 100000!
64 SO = 200000!
66 GO = 20000!
70 FO = 2000!
80 OO = 200
90 CO = 20
95 PO = 2
100 REM Coefficients
105 K0 = 6
110 K1 = .0000004
115 K2 = .000004
117 K3 = .00004
119 K4 = .0004
120 K5 = .004
122 K6 = .04
125 K7 = 3000!
128 K8 = .000004
130 K9 = .002
133 K10 = .02
135 K11 = .2
137 K12 = 2
138 K13 = 20
140 K14 = 1
143 K15 = .00005
145 K16 = .00005
147 K17 = .000001
149 K19 = .000005
152 K20 = .000005
155 K22 = .0000001
158 K23 = .0000005
160 K24 = .0000005
162 K26 = 1E-08
165 K27 = 5E-08
168 K28 = 5E-08
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170 K30 = 1E-09
173 K31 = 5E-09
175 K32 = 5E-09
177 K34 = 1E-10
180 K35 = 1E-10
182 REM Sources
183 I = 1
185 REM Initial conditions
187 S = 1
189 G = 1
191 F = 1
193 O = 1
195 C = 1
197 P = 1
200 REM PLOTTING GRAPHS:
201 IF X = 0 GOTO 245
205 LINE (50,180)-(50,180-5*LOG(S)),3
206 LINE (50,180-5*LOG(S))-(80,180-5*LOG(S)),3
207 LINE (80,180)-(80,180-5*LOG(S)),3
209 LINE (80,180-5*LOG(G))-(110,180-5*LOG(G)),3
210 LINE (110,180)-(110,180-5*LOG(G)),3
212 LINE (110,179-5*LOG(F))-(140,179-5*LOG(F)),3
213 LINE (140,180)-(140,180-5*LOG(F)),3
217 LINE (140,179-5*LOG(O))-(170,179-5*LOG(O)),3
219 LINE (170,179)-(170,179-5*LOG(O)),3
221 LINE (170,179-5*LOG(C))-(200,179-5*LOG(C)),3
224 LINE (200,179)-(200,179-5*LOG(C)),3
226 LINE (200,179-5*LOG(P))-(230,179-5*LOG(P)),3
230 LOCATE 1,30: PRINT T
235 LOCATE 2,30: PRINT " years"
244 IF X = 1 GOTO 300
245 PSET (T/T0,180-S/S0),3
255 PSET (T/T0,150-G/G0),3
265 PSET (T/T0,120-F/F0),3
267 PSET (T/T0, 90-O/O0),3
275 PSET (T/T0, 60-C/C0),3
285 PSET (T/T0, 30-P/P0),3
300 REM Equations
305 R = I/(1 + K0 +K1*S +K2*G +K3*F +K4*O +K5*C +K6*P)
310 JN = (K7*R + K8*RS + K9*R*G +K10*R*F +K11*R*O  + K12*R*C  +K13*R*P)
320 DS = K14*JN - K15*S - K16*S
330 DG = K17*S - K19*G - K20*G
340 DF = K22*G -K23*F - K24*F
350 DO = K26*F - K27*O - K28*O
355 DC = K30*O- K31*C - K32*C
360 DP = K34*C - K35*P
400 REM Change Equations
410 S= S + DS*DT
420 G = G + DG*DT
430 F = F + DF*DT
440 O = O + DO*DT
445 IF O <1 THEN O = 1
450 C = C + DC*DT
455 IF C <1 THEN C = 1
```

```
460 P = P + DP*DT
465 IF P <1 THEN P = 1
470 T = T + DT
500 REM GO BACK AND REPEAT:
505 IF X = 1 GOTO 200
510 IF T/TO < 320 GOTO 200
```


```
 DP*DT
465 IF P <1 THEN P = 1
470 T = T + DT
500 REM GO BACK AND REPEAT:
505 IF X = 1 GOTO 200
510 IF T/TO < 320 GOTO 200
```


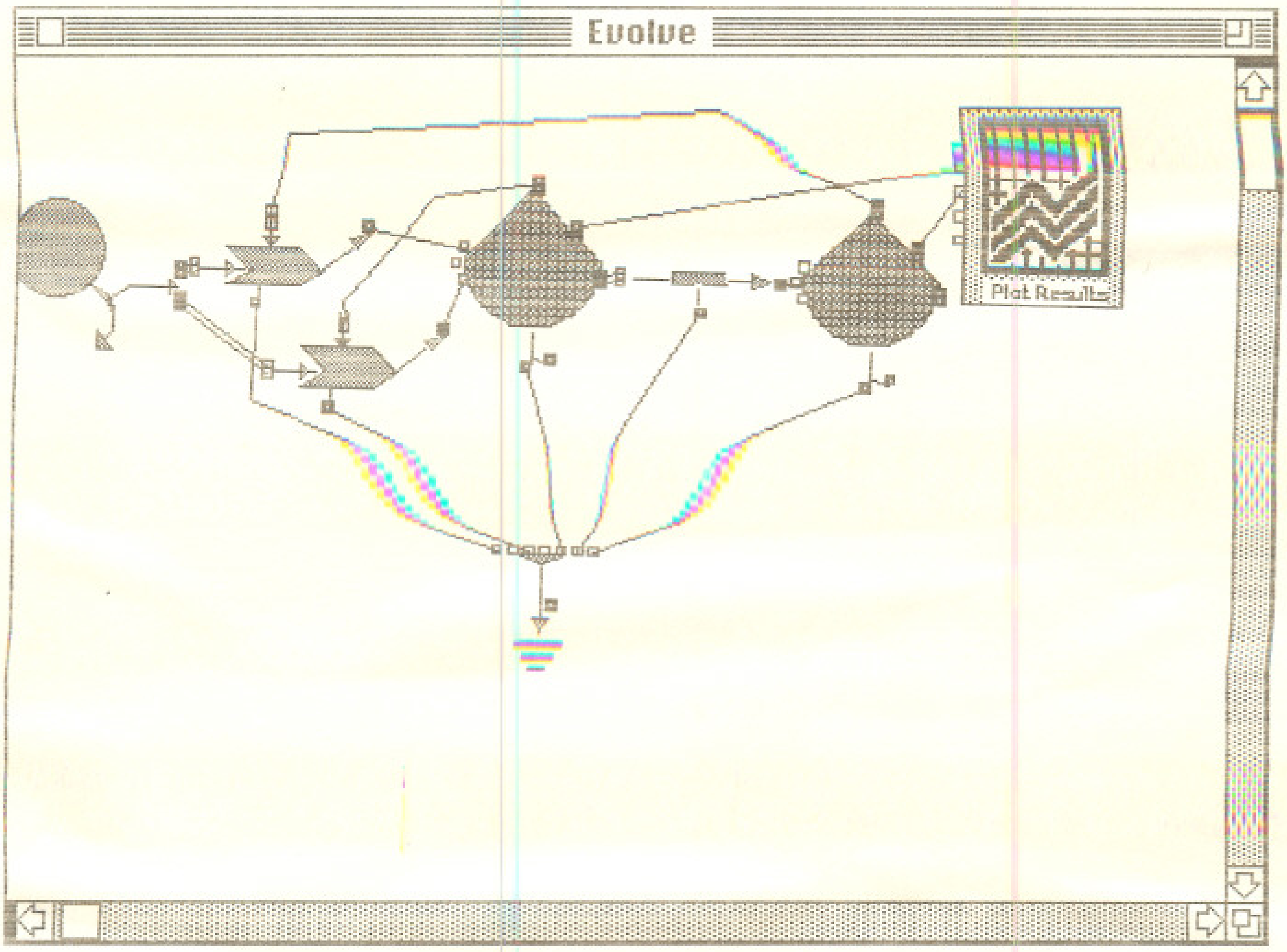

Figure 3. Model of one step of shared information development expressed in energy systems language. This figure is the screen dump print-out of the Macintosh Computer screen with energy language symbols connected for simulation with the graphics simulation program EXTEND.

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