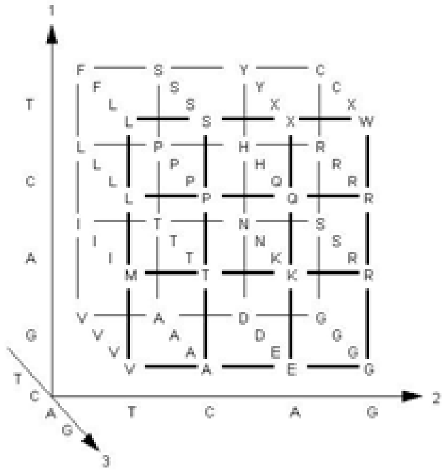
```
(* Singular Value Decomposition (SVD)
  of Amino Acid Hydropathy in the Genetic Code *)
(* Copyright   Doug Youvan   May 30,
 2006    www.youvan.com    www.pseudocolor.com *)

(* Genetic code
```



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 *)

(* 64 codons in binary in canonical order as defined by the following *)

t =.; g =.; c =.; a =.;
nucgc = Tuples[{a, c, g, t}, 3];
a = {0, 0, 0, 1};
c = {0, 0, 1, 0};
g = {0, 1, 0, 0};
t = {1, 0, 0, 0};
nucgc = Flatten[nucgc];
nucgc = Partition[nucgc, 12];

MatrixForm[nucgc]
```

0	0	0	1	0	0	0	1	0	0	0	1
0	0	0	1	0	0	0	1	0	0	1	0
0	0	0	1	0	0	0	1	0	1	0	0
0	0	0	1	0	0	0	1	1	0	0	0
0	0	0	1	0	0	1	0	0	0	0	1
0	0	0	1	0	0	1	0	0	0	1	0
0	0	0	1	0	0	1	0	0	1	0	0
0	0	0	1	0	0	1	0	1	0	0	0
0	0	0	1	0	1	0	0	0	0	0	1
0	0	0	1	0	1	0	0	0	0	1	0
0	0	0	1	0	1	0	0	0	1	0	0
0	0	0	1	0	1	0	0	1	0	0	0
0	0	0	1	1	0	0	0	0	0	0	1
0	0	0	1	1	0	0	0	0	0	1	0
0	0	0	1	1	0	0	0	0	1	0	0
0	0	0	1	1	0	0	0	1	0	0	0

0	0	0	1	1	0	0	0	1	0	0	0
0	0	1	0	0	0	0	1	0	0	0	1
0	0	1	0	0	0	0	1	0	0	1	0
0	0	1	0	0	0	0	1	0	1	0	0
0	0	1	0	0	0	0	1	1	0	0	0
0	0	1	0	0	0	1	0	0	0	0	1
0	0	1	0	0	0	1	0	0	0	1	0
0	0	1	0	0	0	1	0	0	1	0	0
0	0	1	0	0	0	1	0	1	0	0	0
0	0	1	0	0	1	0	0	0	0	0	1
0	0	1	0	0	1	0	0	0	0	1	0
0	0	1	0	0	1	0	0	0	1	0	0
0	0	1	0	0	1	0	0	1	0	0	0
0	0	1	0	1	0	0	0	0	0	0	1
0	0	1	0	1	0	0	0	0	0	1	0
0	0	1	0	1	0	0	0	0	1	0	0
0	0	1	0	1	0	0	0	1	0	0	0
0	1	0	0	0	0	0	1	0	0	0	1
0	1	0	0	0	0	0	1	0	0	1	0
0	1	0	0	0	0	0	1	0	1	0	0
0	1	0	0	0	0	0	1	1	0	0	0
0	1	0	0	0	0	1	0	0	0	0	1
0	1	0	0	0	0	1	0	0	0	1	0
0	1	0	0	0	0	1	0	0	1	0	0
0	1	0	0	0	0	1	0	1	0	0	0
0	1	0	0	0	1	0	0	0	0	0	1
0	1	0	0	0	1	0	0	0	0	1	0
0	1	0	0	0	1	0	0	0	1	0	0
0	1	0	0	0	1	0	0	1	0	0	0
0	1	0	0	1	0	0	0	0	0	0	1
0	1	0	0	1	0	0	0	0	0	1	0
0	1	0	0	1	0	0	0	0	1	0	0
0	1	0	0	1	0	0	0	1	0	0	0
1	0	0	0	0	0	0	1	0	0	0	1
1	0	0	0	0	0	0	1	0	0	1	0
1	0	0	0	0	0	0	1	0	1	0	0
1	0	0	0	0	0	0	1	1	0	0	0
1	0	0	0	0	0	1	0	0	0	0	1
1	0	0	0	0	0	1	0	0	0	1	0
1	0	0	0	0	0	1	0	0	1	0	0
1	0	0	0	0	0	1	0	1	0	0	0
1	0	0	0	0	1	0	0	0	0	0	1
1	0	0	0	0	1	0	0	0	0	1	0
1	0	0	0	0	1	0	0	0	1	0	0
1	0	0	0	0	1	0	0	1	0	0	0
1	0	0	0	1	0	0	0	0	0	0	1
1	0	0	0	1	0	0	0	0	0	1	0
1	0	0	0	1	0	0	0	0	1	0	0
1	0	0	0	1	0	0	0	1	0	0	0

```
(* drop stop codon rows *)

nucgcns = Drop[nucgc, {57}];
nucgcns = Drop[nucgcns, {51}];
nucgcns = Drop[nucgcns, {49}];


(* take pseudoinverse ~ 2 hrs computaton time on Sony VAIO PCG-K64S,
 then hardcode result and comment out PseudoInverse *)
```

```
(* pivns = PseudoInverse[tgcans] *)
```

```
pivns =
```

$$\Big\{\Big\{\frac{1}{684}, -\frac{131}{16416}, -\frac{7}{2052}, -\frac{131}{16416}, -\frac{131}{16416}, -\frac{143}{8208}, -\frac{211}{16416}, -\frac{143}{8208},$$
$$-\frac{7}{2052}, -\frac{211}{16416}, -\frac{17}{2052}, -\frac{211}{16416}, -\frac{131}{16416}, -\frac{143}{8208}, -\frac{211}{16416}, -\frac{143}{8208}, \frac{1}{684},$$
$$-\frac{131}{16416}, -\frac{7}{2052}, -\frac{131}{16416}, -\frac{131}{16416}, -\frac{143}{8208}, -\frac{211}{16416}, -\frac{143}{8208}, -\frac{7}{2052},$$
$$-\frac{211}{16416}, -\frac{17}{2052}, -\frac{211}{16416}, -\frac{131}{16416}, -\frac{143}{8208}, -\frac{211}{16416}, -\frac{143}{8208}, \frac{1}{684},$$
$$-\frac{131}{16416}, -\frac{7}{2052}, -\frac{131}{16416}, -\frac{131}{16416}, -\frac{143}{8208}, -\frac{211}{16416}, -\frac{143}{8208}, -\frac{7}{2052},$$
$$-\frac{211}{16416}, -\frac{17}{2052}, -\frac{211}{16416}, -\frac{131}{16416}, -\frac{143}{8208}, -\frac{211}{16416}, -\frac{143}{8208}, \frac{125}{1824}, \frac{125}{1824},$$
$$\frac{125}{1824}, \frac{485}{8208}, \frac{55}{864}, \frac{485}{8208}, \frac{55}{864}, \frac{35}{513}, \frac{55}{864}, \frac{125}{1824}, \frac{485}{8208}, \frac{55}{864}, \frac{485}{8208}\Big\},$$
$$\Big\{-\frac{35}{2736}, -\frac{179}{16416}, -\frac{97}{8208}, -\frac{179}{16416}, -\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, -\frac{37}{4104},$$
$$-\frac{97}{8208}, -\frac{163}{16416}, -\frac{89}{8208}, -\frac{163}{16416}, -\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, -\frac{37}{4104},$$
$$-\frac{35}{2736}, -\frac{179}{16416}, -\frac{97}{8208}, -\frac{179}{16416}, -\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, -\frac{37}{4104},$$
$$-\frac{97}{8208}, -\frac{163}{16416}, -\frac{89}{8208}, -\frac{163}{16416}, -\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, -\frac{37}{4104}, \frac{17}{342},$$
$$\frac{847}{16416}, \frac{26}{513}, \frac{847}{16416}, \frac{847}{16416}, \frac{439}{8208}, \frac{863}{16416}, \frac{439}{8208}, \frac{26}{513}, \frac{863}{16416}, \frac{53}{1026},$$
$$\frac{863}{16416}, \frac{847}{16416}, \frac{439}{8208}, \frac{863}{16416}, \frac{439}{8208}, -\frac{25}{1824}, -\frac{25}{1824}, -\frac{25}{1824}, -\frac{97}{8208},$$
$$-\frac{11}{864}, -\frac{97}{8208}, -\frac{11}{864}, -\frac{7}{513}, -\frac{11}{864}, -\frac{25}{1824}, -\frac{97}{8208}, -\frac{11}{864}, -\frac{97}{8208}\Big\},$$
$$\Big\{-\frac{35}{2736}, -\frac{179}{16416}, -\frac{97}{8208}, -\frac{179}{16416}, -\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, -\frac{37}{4104},$$
$$-\frac{97}{8208}, -\frac{163}{16416}, -\frac{89}{8208}, -\frac{163}{16416}, -\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, -\frac{37}{4104},$$
$$\frac{17}{342}, \frac{847}{16416}, \frac{26}{513}, \frac{847}{16416}, \frac{847}{16416}, \frac{439}{8208}, \frac{863}{16416}, \frac{439}{8208}, \frac{26}{513}, \frac{863}{16416},$$
$$\frac{53}{1026}, \frac{863}{16416}, \frac{847}{16416}, \frac{439}{8208}, \frac{863}{16416}, \frac{439}{8208}, -\frac{35}{2736}, -\frac{179}{16416}, -\frac{97}{8208},$$
$$-\frac{179}{16416}, -\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, -\frac{37}{4104}, -\frac{97}{8208}, -\frac{163}{16416}, -\frac{89}{8208},$$
$$-\frac{163}{16416}, -\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, -\frac{37}{4104}, -\frac{25}{1824}, -\frac{25}{1824}, -\frac{25}{1824}, -\frac{97}{8208},$$
$$-\frac{11}{864}, -\frac{97}{8208}, -\frac{11}{864}, -\frac{7}{513}, -\frac{11}{864}, -\frac{25}{1824}, -\frac{97}{8208}, -\frac{11}{864}, -\frac{97}{8208}\Big\},$$
$$\Big\{\frac{17}{342}, \frac{847}{16416}, \frac{26}{513}, \frac{847}{16416}, \frac{847}{16416}, \frac{439}{8208}, \frac{863}{16416}, \frac{439}{8208}, \frac{26}{513}, \frac{863}{16416},$$
$$\frac{53}{1026}, \frac{863}{16416}, \frac{847}{16416}, \frac{439}{8208}, \frac{863}{16416}, \frac{439}{8208}, -\frac{35}{2736}, -\frac{179}{16416}, -\frac{97}{8208},$$
$$-\frac{179}{16416}, -\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, -\frac{37}{4104}, -\frac{97}{8208}, -\frac{163}{16416}, -\frac{89}{8208},$$
$$-\frac{163}{16416}, -\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, -\frac{37}{4104}, -\frac{35}{2736}, -\frac{179}{16416}, -\frac{97}{8208},$$
$$-\frac{179}{16416}, -\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, -\frac{37}{4104}, -\frac{97}{8208}, -\frac{163}{16416}, -\frac{89}{8208},$$

$$-\frac{163}{16416}, -\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, -\frac{37}{4104}, -\frac{25}{1824}, -\frac{25}{1824}, -\frac{25}{1824}, -\frac{97}{8208},$$
$$-\frac{11}{864}, -\frac{97}{8208}, -\frac{11}{864}, -\frac{7}{513}, -\frac{11}{864}, -\frac{25}{1824}, -\frac{97}{8208}, -\frac{11}{864}, -\frac{97}{8208}\},$$
$$\{-\frac{35}{2736}, -\frac{179}{16416}, -\frac{97}{8208}, -\frac{179}{16416}, -\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, -\frac{37}{4104},$$
$$-\frac{97}{8208}, -\frac{163}{16416}, -\frac{89}{8208}, -\frac{163}{16416}, \frac{847}{16416}, \frac{439}{8208}, \frac{863}{16416}, \frac{439}{8208}, -\frac{35}{2736},$$
$$-\frac{179}{16416}, -\frac{97}{8208}, -\frac{179}{16416}, -\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, -\frac{37}{4104}, -\frac{97}{8208},$$
$$-\frac{163}{16416}, -\frac{89}{8208}, -\frac{163}{16416}, \frac{847}{16416}, \frac{439}{8208}, \frac{863}{16416}, \frac{439}{8208}, -\frac{35}{2736}, -\frac{179}{16416},$$
$$-\frac{97}{8208}, -\frac{179}{16416}, -\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, -\frac{37}{4104}, -\frac{97}{8208}, -\frac{163}{16416},$$
$$-\frac{89}{8208}, -\frac{163}{16416}, \frac{847}{16416}, \frac{439}{8208}, \frac{863}{16416}, \frac{439}{8208}, -\frac{25}{1824}, -\frac{25}{1824}, -\frac{25}{1824},$$
$$-\frac{97}{8208}, -\frac{11}{864}, -\frac{97}{8208}, -\frac{11}{864}, -\frac{7}{513}, -\frac{11}{864}, \frac{89}{1824}, \frac{26}{513}, \frac{43}{864}, \frac{26}{513}\},$$
$$\{-\frac{13}{1368}, -\frac{739}{57456}, -\frac{389}{28728}, -\frac{739}{57456}, -\frac{965}{114912}, -\frac{193}{16416}, -\frac{1429}{114912}, -\frac{193}{16416},$$
$$\frac{1663}{28728}, \frac{3133}{57456}, \frac{221}{4104}, \frac{3133}{57456}, -\frac{965}{114912}, -\frac{193}{16416}, -\frac{1429}{114912}, -\frac{193}{16416}, -\frac{13}{1368},$$
$$-\frac{739}{57456}, -\frac{389}{28728}, -\frac{739}{57456}, -\frac{965}{114912}, -\frac{193}{16416}, -\frac{1429}{114912}, -\frac{193}{16416}, \frac{1663}{28728},$$
$$\frac{3133}{57456}, \frac{221}{4104}, \frac{3133}{57456}, -\frac{965}{114912}, -\frac{193}{16416}, -\frac{1429}{114912}, -\frac{193}{16416}, -\frac{13}{1368}, -\frac{739}{57456},$$
$$-\frac{389}{28728}, -\frac{739}{57456}, -\frac{965}{114912}, -\frac{193}{16416}, -\frac{1429}{114912}, -\frac{193}{16416}, \frac{1663}{28728}, \frac{3133}{57456}, \frac{221}{4104},$$
$$\frac{3133}{57456}, -\frac{965}{114912}, -\frac{193}{16416}, -\frac{1429}{114912}, -\frac{193}{16416}, -\frac{65}{6384}, -\frac{65}{6384}, -\frac{73}{12768}, -\frac{149}{16416},$$
$$-\frac{59}{6048}, -\frac{149}{16416}, \frac{173}{3024}, \frac{29}{513}, \frac{173}{3024}, -\frac{73}{12768}, -\frac{149}{16416}, -\frac{59}{6048}, -\frac{149}{16416}\},$$
$$\{-\frac{35}{2736}, -\frac{179}{16416}, -\frac{97}{8208}, -\frac{179}{16416}, \frac{847}{16416}, \frac{439}{8208}, \frac{863}{16416}, \frac{439}{8208}, -\frac{97}{8208},$$
$$-\frac{163}{16416}, -\frac{89}{8208}, -\frac{163}{16416}, -\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, -\frac{37}{4104}, -\frac{35}{2736},$$
$$-\frac{179}{16416}, -\frac{97}{8208}, -\frac{179}{16416}, \frac{847}{16416}, \frac{439}{8208}, \frac{863}{16416}, \frac{439}{8208}, -\frac{97}{8208}, -\frac{163}{16416},$$
$$-\frac{89}{8208}, -\frac{163}{16416}, -\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, -\frac{37}{4104}, -\frac{35}{2736}, -\frac{179}{16416},$$
$$-\frac{97}{8208}, -\frac{179}{16416}, \frac{847}{16416}, \frac{439}{8208}, \frac{863}{16416}, \frac{439}{8208}, -\frac{97}{8208}, -\frac{163}{16416}, -\frac{89}{8208},$$
$$-\frac{163}{16416}, -\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, -\frac{37}{4104}, -\frac{25}{1824}, -\frac{25}{1824}, \frac{89}{1824},$$
$$\frac{26}{513}, \frac{43}{864}, \frac{26}{513}, -\frac{11}{864}, -\frac{7}{513}, -\frac{11}{864}, -\frac{25}{1824}, -\frac{97}{8208}, -\frac{11}{864}, -\frac{97}{8208}\},$$
$$\{\frac{83}{1368}, \frac{3245}{57456}, \frac{1747}{28728}, \frac{3245}{57456}, -\frac{1205}{114912}, -\frac{241}{16416}, -\frac{1189}{114912}, -\frac{241}{16416}, -\frac{305}{28728},$$
$$-\frac{851}{57456}, -\frac{43}{4104}, -\frac{851}{57456}, -\frac{1205}{114912}, -\frac{241}{16416}, -\frac{1189}{114912}, -\frac{241}{16416}, \frac{83}{1368}, \frac{3245}{57456},$$
$$\frac{1747}{28728}, \frac{3245}{57456}, -\frac{1205}{114912}, -\frac{241}{16416}, -\frac{1189}{114912}, -\frac{241}{16416}, -\frac{305}{28728}, -\frac{851}{57456},$$
$$-\frac{43}{4104}, -\frac{851}{57456}, -\frac{1205}{114912}, -\frac{241}{16416}, -\frac{1189}{114912}, -\frac{241}{16416}, \frac{83}{1368}, \frac{3245}{57456}, \frac{1747}{28728},$$
$$\frac{3245}{57456}, -\frac{1205}{114912}, -\frac{241}{16416}, -\frac{1189}{114912}, -\frac{241}{16416}, -\frac{305}{28728}, -\frac{851}{57456}, -\frac{43}{4104},$$
$$-\frac{851}{57456}, -\frac{1205}{114912}, -\frac{241}{16416}, -\frac{1189}{114912}, -\frac{241}{16416}, \frac{415}{6384}, \frac{415}{6384}, -\frac{25}{12768}, -\frac{101}{16416},$$

$$-\frac{11}{6048}, -\frac{101}{16416}, -\frac{19}{3024}, -\frac{1}{513}, -\frac{19}{3024}, -\frac{25}{12768}, -\frac{101}{16416}, -\frac{11}{6048}, -\frac{101}{16416}\},$$
$$\{-\frac{35}{2736}, -\frac{179}{16416}, -\frac{97}{8208}, \frac{847}{16416}, -\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, \frac{439}{8208}, -\frac{97}{8208}, -\frac{163}{16416},$$
$$-\frac{89}{8208}, \frac{863}{16416}, -\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, \frac{439}{8208}, -\frac{35}{2736}, -\frac{179}{16416}, -\frac{97}{8208}, \frac{847}{16416},$$
$$-\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, \frac{439}{8208}, -\frac{97}{8208}, -\frac{163}{16416}, -\frac{89}{8208}, \frac{863}{16416}, -\frac{179}{16416}, -\frac{37}{4104},$$
$$-\frac{163}{16416}, \frac{439}{8208}, -\frac{35}{2736}, -\frac{179}{16416}, -\frac{97}{8208}, \frac{847}{16416}, -\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, \frac{439}{8208},$$
$$-\frac{97}{8208}, -\frac{163}{16416}, -\frac{89}{8208}, \frac{863}{16416}, -\frac{179}{16416}, -\frac{37}{4104}, -\frac{163}{16416}, \frac{439}{8208}, -\frac{25}{1824}, \frac{89}{1824},$$
$$-\frac{25}{1824}, -\frac{97}{8208}, -\frac{11}{864}, \frac{26}{513}, -\frac{11}{864}, -\frac{7}{513}, \frac{43}{864}, -\frac{25}{1824}, -\frac{97}{8208}, -\frac{11}{864}, \frac{26}{513}\},$$
$$\{-\frac{13}{1368}, -\frac{965}{114912}, \frac{1663}{28728}, -\frac{965}{114912}, -\frac{739}{57456}, -\frac{193}{16416}, \frac{3133}{57456}, -\frac{193}{16416},$$
$$-\frac{389}{28728}, -\frac{1429}{114912}, \frac{221}{4104}, -\frac{1429}{114912}, -\frac{739}{57456}, -\frac{193}{16416}, \frac{3133}{57456}, -\frac{193}{16416}, -\frac{13}{1368},$$
$$-\frac{965}{114912}, \frac{1663}{28728}, -\frac{965}{114912}, -\frac{739}{57456}, -\frac{193}{16416}, \frac{3133}{57456}, -\frac{193}{16416}, -\frac{389}{28728},$$
$$-\frac{1429}{114912}, \frac{221}{4104}, -\frac{1429}{114912}, -\frac{739}{57456}, -\frac{193}{16416}, \frac{3133}{57456}, -\frac{193}{16416}, -\frac{13}{1368}, -\frac{965}{114912},$$
$$\frac{1663}{28728}, -\frac{965}{114912}, -\frac{739}{57456}, -\frac{193}{16416}, \frac{3133}{57456}, -\frac{193}{16416}, -\frac{389}{28728}, -\frac{1429}{114912},$$
$$\frac{221}{4104}, -\frac{1429}{114912}, -\frac{739}{57456}, -\frac{193}{16416}, \frac{3133}{57456}, -\frac{193}{16416}, -\frac{73}{12768}, -\frac{73}{12768}, -\frac{65}{6384},$$
$$-\frac{149}{16416}, \frac{173}{3024}, -\frac{149}{16416}, -\frac{59}{6048}, \frac{29}{513}, -\frac{59}{6048}, -\frac{65}{6384}, -\frac{149}{16416}, \frac{173}{3024}, -\frac{149}{16416}\},$$
$$\{-\frac{35}{2736}, \frac{847}{16416}, -\frac{97}{8208}, -\frac{179}{16416}, -\frac{179}{16416}, \frac{439}{8208}, -\frac{163}{16416}, -\frac{37}{4104}, -\frac{97}{8208}, \frac{863}{16416},$$
$$-\frac{89}{8208}, -\frac{163}{16416}, -\frac{179}{16416}, \frac{439}{8208}, -\frac{163}{16416}, -\frac{37}{4104}, -\frac{35}{2736}, \frac{847}{16416}, -\frac{97}{8208}, -\frac{179}{16416},$$
$$-\frac{179}{16416}, \frac{439}{8208}, -\frac{163}{16416}, -\frac{37}{4104}, -\frac{97}{8208}, \frac{863}{16416}, -\frac{89}{8208}, -\frac{163}{16416}, -\frac{179}{16416}, \frac{439}{8208},$$
$$-\frac{163}{16416}, -\frac{37}{4104}, -\frac{35}{2736}, \frac{847}{16416}, -\frac{97}{8208}, -\frac{179}{16416}, -\frac{179}{16416}, \frac{439}{8208}, -\frac{163}{16416}, -\frac{37}{4104},$$
$$-\frac{97}{8208}, \frac{863}{16416}, -\frac{89}{8208}, -\frac{163}{16416}, -\frac{179}{16416}, \frac{439}{8208}, -\frac{163}{16416}, -\frac{37}{4104}, \frac{89}{1824}, -\frac{25}{1824},$$
$$-\frac{25}{1824}, \frac{26}{513}, -\frac{11}{864}, -\frac{97}{8208}, \frac{43}{864}, -\frac{7}{513}, -\frac{11}{864}, -\frac{25}{1824}, \frac{26}{513}, -\frac{11}{864}, -\frac{97}{8208}\},$$
$$\{\frac{83}{1368}, -\frac{1205}{114912}, -\frac{305}{28728}, -\frac{1205}{114912}, \frac{3245}{57456}, -\frac{241}{16416}, -\frac{851}{57456}, -\frac{241}{16416},$$
$$\frac{1747}{28728}, -\frac{1189}{114912}, -\frac{43}{4104}, -\frac{1189}{114912}, \frac{3245}{57456}, -\frac{241}{16416}, -\frac{851}{57456}, -\frac{241}{16416}, \frac{83}{1368},$$
$$-\frac{1205}{114912}, -\frac{305}{28728}, -\frac{1205}{114912}, \frac{3245}{57456}, -\frac{241}{16416}, -\frac{851}{57456}, -\frac{241}{16416}, \frac{1747}{28728},$$
$$-\frac{1189}{114912}, -\frac{43}{4104}, -\frac{1189}{114912}, \frac{3245}{57456}, -\frac{241}{16416}, -\frac{851}{57456}, -\frac{241}{16416}, \frac{83}{1368}, -\frac{1205}{114912},$$
$$-\frac{305}{28728}, -\frac{1205}{114912}, \frac{3245}{57456}, -\frac{241}{16416}, -\frac{851}{57456}, -\frac{241}{16416}, \frac{1747}{28728}, -\frac{1189}{114912}, -\frac{43}{4104},$$
$$-\frac{1189}{114912}, \frac{3245}{57456}, -\frac{241}{16416}, -\frac{851}{57456}, -\frac{241}{16416}, -\frac{25}{12768}, -\frac{25}{12768}, \frac{415}{6384}, -\frac{101}{16416},$$
$$-\frac{19}{3024}, -\frac{101}{16416}, -\frac{11}{6048}, -\frac{1}{513}, -\frac{11}{6048}, \frac{415}{6384}, -\frac{101}{16416}, -\frac{19}{3024}, -\frac{101}{16416}\}\};$$

```
(* codon triplets entered manually in canonical order by alphabet -
  as above in nucgc matrix

  AAA
  AAC
  AAG
  AAT
  ACA
  ACC
  ACG
  ACT
  AGA
  AGC
  AGG
  AGT
  ATA
  ATC
  ATG
  ATT
  CAA
  CAC
  CAG
  CAT
  CCA
  CCC
  CCG
  CCT
  CGA
  CGC
  CGG
  CGT
  CTA
  CTC
  CTG
  CTT
  GAA
  GAC
  GAG
  GAT
  GCA
  GCC
  GCG
  GCT
  GGA
  GGC
  GGG
  GGT
  GTA
  GTC
  GTG
  GTT
  TAA
  TAC
```

```
TAG
TAT
TCA
TCC
TCG
TCT
TGA
TGC
TGG
TGT
TTA
TTC
TTG
TTT

manually copy the triplets from above and
replace with amino acid single letter code, in identical order,
and make matrix ' aagcns' for amino acid genetic code, delete 3 stop codons *)

aagcns =
 {k,
  n,
  k,
  n,
  t,
  t,
  t,
  t,
  r,
  s,
  r,
  s,
  i,
  i,
  m,
  i,
  q,
  h,
  q,
  h,
  p,
  p,
  p,
  p,
  r,
  r,
  r,
  r,
  l,
  l,
  l,
  l,
  e,
  d,
  e,
```

```
d,
a,
a,
a,
a,
g,
g,
g,
g,
v,
v,
v,
v,
y,
y,
s,
s,
s,
s,
c,
w,
c,
l,
f,
l,
f};
```

```
(* hotmap *)

hotmap = Table[{
     Piecewise[{
       {1,  1 <= i < 42},
       {1, 42 <= i < 84},
       {Floor[5.8 * (i - 83)], 84 <= i < 128},
       {256, 128  <= i < 170},
       {256, 170 <= i < 212},
       {256, 212 <= i <= 256}
      }],
     Piecewise[{
       {1,  1 <= i < 42},
       {(i - 41) * 6, 42 <= i < 84},
       {256, 84 <= i < 128},
       {256 - (i - 128) * 6, 128  <= i < 170},
       {1, 170 <= i < 212},
       {Floor[(i - 211) * 5.7], 212 <= i <= 256}
      }],
     Piecewise[{
       {Floor[i * 5.8], 1 <= i < 42},
       {256 - ((i - 42) * 6), 42 <= i < 84},
       {1, 84 <= i < 128},
       {1, 128  <= i < 170},
       {(i - 169) * 6, 170 <= i < 212},
       {256, 212 <= i <= 256}
      }]
    },
    {i, 1, 256, 1}];

 hotmap[[1, All]] = 1 ;
 (* This changes 1,1,5 to 1,1,1 at i=1 for the blue channel *)

 (* Pseudocolor 61 x 12 pivns matrix *)

 (* get scaling factors *)

graymat  = pivns;
 graymin = Min[graymat]
 graymax = Max[graymat]
 delta  = graymax - graymin
```

$-\frac{143}{8208}$

$\frac{125}{1824}$

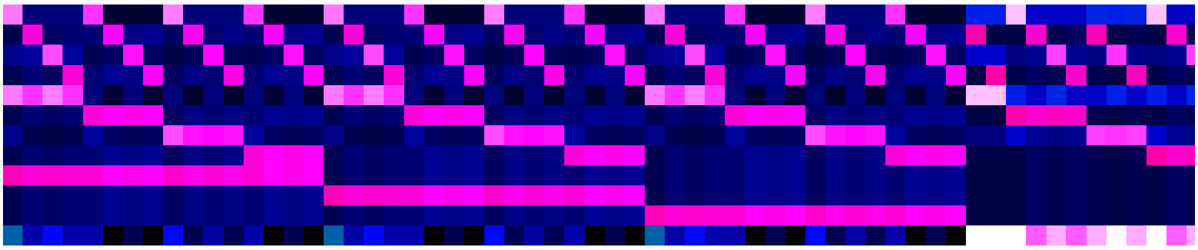
$\frac{1411}{16416}$

```
(* rescale graymat according to min max to get grayscales of 1 to 256 *)

For[x = 1, x ≤ 12, x++,
  For[y = 1, y ≤ 61, y++,
   graymat[[x, y]] = Floor[(graymat[[x, y]] - (graymin)) * (255 / delta) + 1] ]];

colormat = Table[{x, y}, {x, 12}, {y, 61}];
colormat[[All, All]] = {0, 0, 0};
For[x = 1, x ≤ 12, x++,
  For[y = 1, y ≤ 61, y++,
   colormat[[x, y]] = hotmap[[graymat[[x, y]] ]] / 256
  ]];

gmat = Graphics[RasterArray[Apply[RGBColor, colormat, {2}]],
   ImageSize → {10 * 61, 10 * 12}, AspectRatio → Automatic];
Show[
  gmat];
```



```
(* Map an attribute of the amino acids onto the triplet codons *)

jjt =.
a =.; c =.; d =.; e =.; f =.; g =.; h =.; i =.; k =.; l =.;
m =.; n =.; p =.; q =.; r =.; s =.; t =.; v =.; w =.; y =.;
jjt = {{k}, {n}, {k}, {n}, {t}, {t}, {t}, {t}, {r}, {s}, {r}, {s}, {i}, {i}, {m}, {i},
   {q}, {h}, {q}, {h}, {p}, {p}, {p}, {p}, {r}, {r}, {r}, {r}, {l}, {l}, {l},
   {l}, {e}, {d}, {e}, {d}, {a}, {a}, {a}, {a}, {g}, {g}, {g}, {g}, {v}, {v},
   {v}, {v}, {y}, {y}, {s}, {s}, {s}, {s}, {c}, {w}, {c}, {l}, {f}, {l}, {f}};

nuchyd =.
(* symbolic *)
nuchyd = pivns.jjt;
MatrixForm[nuchyd]
```

$$
\begin{pmatrix}
-\frac{457 a}{8208}+\frac{55 c}{432}-\frac{131 d}{8208}-\frac{e}{513}+\frac{485 f}{4104}-\frac{307 g}{8208}-\frac{131 h}{8208}-\frac{37 i}{864}-\frac{k}{513}+\frac{157 l}{2052}-\frac{211 m}{16416}-\frac{131 n}{8208}-\frac{457 p}{8208}-\frac{q}{513}-\cdots \\
\frac{1733 a}{8208}-\frac{11 c}{432}+\frac{847 d}{8208}+\frac{103 e}{1026}-\frac{97 f}{4104}+\frac{1703 g}{8208}-\frac{179 h}{8208}-\frac{25 i}{864}-\frac{101 k}{4104}-\frac{67 l}{1026}-\frac{163 m}{16416}-\frac{179 n}{8208}-\frac{319 p}{8208}-\frac{101 q}{4104}\cdots \\
-\frac{319 a}{8208}-\frac{11 c}{432}-\frac{179 d}{8208}-\frac{101 e}{4104}-\frac{97 f}{4104}-\frac{349 g}{8208}+\frac{847 h}{8208}-\frac{25 i}{864}-\frac{101 k}{4104}+\frac{379 l}{2052}-\frac{163 m}{16416}-\frac{179 n}{8208}+\frac{1733 p}{8208}+\frac{103 q}{1026}\cdots \\
-\frac{319 a}{8208}-\frac{11 c}{432}-\frac{179 d}{8208}-\frac{101 e}{4104}-\frac{97 f}{4104}-\frac{349 g}{8208}-\frac{179 h}{8208}+\frac{137 i}{864}+\frac{103 k}{1026}-\frac{67 l}{1026}+\frac{863 m}{16416}+\frac{847 n}{8208}-\frac{319 p}{8208}-\frac{101 q}{4104}\cdots \\
-\frac{319 a}{8208}-\frac{11 c}{432}-\frac{179 d}{8208}-\frac{101 e}{4104}+\frac{52 f}{513}-\frac{349 g}{8208}-\frac{179 h}{8208}+\frac{137 i}{864}-\frac{101 k}{4104}+\frac{1271 l}{4104}+\frac{863 m}{16416}-\frac{179 n}{8208}-\frac{319 p}{8208}-\frac{101 q}{4104}\cdots \\
-\frac{91 a}{2052}+\frac{173 c}{1512}-\frac{739 d}{28728}-\frac{331 e}{14364}-\frac{149 f}{8208}+\frac{6343 g}{28728}-\frac{739 h}{28728}-\frac{193 i}{6048}-\frac{331 k}{14364}-\frac{491 l}{8208}-\frac{1429 m}{114912}-\frac{739 n}{28728}-\frac{91 p}{2052}-\cdots \\
\frac{1733 a}{8208}-\frac{11 c}{432}-\frac{179 d}{8208}-\frac{101 e}{4104}-\frac{97 f}{4104}-\frac{349 g}{8208}-\frac{179 h}{8208}-\frac{25 i}{864}-\frac{101 k}{4104}-\frac{67 l}{1026}-\frac{163 m}{16416}-\frac{179 n}{8208}+\frac{1733 p}{8208}-\frac{101 q}{4104}\cdots \\
-\frac{103 a}{2052}-\frac{19 c}{1512}+\frac{3245 d}{28728}+\frac{1745 e}{14364}-\frac{101 f}{8208}-\frac{1457 g}{28728}+\frac{3245 h}{28728}-\frac{241 i}{6048}+\frac{1745 k}{14364}-\frac{443 l}{8208}-\frac{1189 m}{114912}+\frac{3245 n}{28728}-\frac{103 p}{2052}\cdots \\
\frac{97 a}{4104}+\frac{c}{27}+\frac{167 d}{4104}-\frac{101 e}{4104}+\frac{319 f}{8208}+\frac{41 g}{2052}+\frac{167 h}{4104}+\frac{29 i}{864}-\frac{101 k}{4104}-\frac{23 l}{8208}-\frac{163 m}{16416}+\frac{167 n}{4104}+\frac{97 p}{4104}-\frac{101 q}{4104}-\cdots \\
\frac{149 a}{8208}-\frac{59 c}{3024}-\frac{965 d}{57456}+\frac{695 e}{14364}-\frac{149 f}{8208}+\frac{887 g}{57456}-\frac{965 h}{57456}-\frac{55 i}{1512}+\frac{695 k}{14364}+\frac{535 l}{8208}+\frac{3133 m}{57456}-\frac{965 n}{57456}+\frac{149 p}{8208}+\cdots \\
\frac{97 a}{4104}+\frac{c}{27}+\frac{167 d}{4104}-\frac{101 e}{4104}+\frac{319 f}{8208}+\frac{41 g}{2052}+\frac{167 h}{4104}+\frac{29 i}{864}-\frac{101 k}{4104}-\frac{23 l}{8208}-\frac{163 m}{16416}+\frac{167 n}{4104}+\frac{97 p}{4104}-\frac{101 q}{4104}-\cdots \\
\frac{101 a}{8208}-\frac{11 c}{3024}-\frac{1205 d}{57456}+\frac{719 e}{14364}-\frac{101 f}{8208}+\frac{1703 g}{57456}-\frac{1205 h}{57456}+\frac{41 i}{1512}+\frac{719 k}{14364}+\frac{583 l}{8208}-\frac{851 m}{57456}-\frac{1205 n}{57456}+\frac{101 p}{8208}+\cdots
\end{pmatrix}
$$

```
(* 20 empirical observed values for propensity to be in a membrane,
 i.e., hydropathy values*)

a =  1.37;
c = 1.12;
d = 0.17;
e = 0.16;
f = 1.93;
g = 1.03;
h = 0.74;
i = 2.20;
k = 0.19;
l = 1.78;
m = 1.39;
n =  0.43;
p =  0.51;
q =  0.35;
r =  0.30;
s =  0.83;
t =  0.89;
v = 1.81;
w = 1.56;
y = 1.01;

nuchyd (* numeric with above hydropathy values *)
```

```
{{0.495109}, {0.431103}, {0.121103}, {0.277978}, {1.19798}, {0.10284},
 {0.237353}, {-0.212878}, {0.396728}, {0.261992}, {0.396728}, {0.269845}}
```

```
(* Reconstruct hydropathy values from nucleotide
  information using dot product of a weighted vector for triplets *)
(* use single letter code for new vectors, precede by the letter ' a',
 because variables are global *)

(* a=
   {{0,1,0,0,     0,0,1,0,     1,0,0,0},
    {0,1,0,0,     0,0,1,0,     0,1,0,0},
    {0,1,0,0,     0,0,1,0,     0,0,1,0},
    {0,1,0,0,     0,0,1,0,     0,0,0,1}}; *)

aa = {0, 1, 0, 0,    0, 0, 1, 0,  .25, .25, .25, .25};
aanuc = Total[aa.nuchyd, 2]
```

```
0.99978
```

```
(* c=
   {{1,0,0,0,     0,1,0,0,     1,0,0,0},
    {1,0,0,0,     0,1,0,0,     0,0,1,0}}; *)

ac = {1, 0, 0, 0,  0, 1, 0, 0,  0.5, 0, 0.5, 0};
acnuc = Total[ac.nuchyd, 2]
```

0.994678

```
(* d=
   {{0,1,0,0,      0,0,0,1,     0,0,1,0},
      {0,1,0,0,     0,0,0,1,     1,0,0,0}}; *)

ad = {0, 1, 0, 0,  0, 0, 0, 1,  0.5, 0, 0.5, 0};

adnuc = Total[ad.nuchyd, 2]
```

0.614953

```
(* e={{0,1,0,0,      0,0,0,1,     0,0,0,1},
      {0,1,0,0,      0,0,0,1,     0,1,0,0}}; *)

ae = {0, 1, 0, 0,  0, 0, 0, 1,  0, .5, 0, .5};

aenuc = Total[ae.nuchyd, 2]
```

0.484144

```
(*  f={{1,0,0,0,     1,0,0,0,     1,0,0,0},
       {1,0,0,0,     1,0,0,0,     0,0,1,0}};  *)

af = {1, 0, 0, 0,   1, 0, 0, 0,   1, 0, 1, 0};
afnuc = Total[af.nuchyd, 2]
```

2.48654

```
(*g=
   {{0,1,0,0,     0,1,0,0,     1,0,0,0},
    {0,1,0,0,     0,1,0,0,     0,1,0,0},
    {0,1,0,0,     0,1,0,0,     0,0,1,0},
    {0,1,0,0,     0,1,0,0,     0,0,0,1}};  *)

ag = {0, 1, 0, 0,   0, 1, 0, 0,   .25, .25, .25, .25};
agnuc = Total[ag.nuchyd, 2]
```

0.865267

```
(* h=
   {{0,0,1,0,     0,0,0,1,     1,0,0,0},
    {0,0,1,0,     0,0,0,1,     0,0,1,0}}; *)

ah = {0, 0, 1, 0,   0, 0, 0, 1,   .5, 0, .5, 0};
ahnuc = Total[ah.nuchyd, 2]
```

0.304953

```
(* i=
   {{0,0,0,1,     1,0,0,0,     1,0,0,0},
    {0,0,0,1,     1,0,0,0,     0,0,1,0},
    {0,0,0,1,     1,0,0,0,     0,0,0,1}}; *)

ai = {0, 0, 0, 1,   1, 0, 0, 0,   1/3, 0, 1/3, 1/3};
ainuc = Total[ai.nuchyd, 2]
```

1.83039

```
(* k=
   {{0,0,0,1,     0,0,0,1,     0,1,0,0},
    {0,0,0,1,     0,0,0,1,     0,0,0,1}}; *)

ak = {0, 0, 0, 1,   0, 0, 0, 1,   0, .5, 0, .5};
aknuc = Total[ak.nuchyd, 2]
```

0.331019

```
(* l=
   {{0,0,1,0,     1,0,0,0,     1,0,0,0},
    {0,0,1,0,     1,0,0,0,     0,1,0,0},
    {0,0,1,0,     1,0,0,0,     0,0,1,0},
    {0,0,1,0,     1,0,0,0,     0,0,0,1},

    {1,0,0,0,     1,0,0,0,     0,1,0,0},
    {1,0,0,0,     1,0,0,0,     0,0,0,1}}; *)

al = {.33, 0, .66, 0,   1, 0, 0, 0,   1/6, 2/6, 1/6, 2/6};
alnuc = Total[al.nuchyd, 2]
```

1.75081

```
(* m=
   {{0,0,0,1,     1,0,0,0,     0,1,0,0}}; *)

am = {0, 0, 0, 1,   1, 0, 0, 0,   0, 1, 0, 0};
amnuc = Total[am.nuchyd, 2]
```

1.73795

```
(* n=
   {{0,0,0,1,     0,0,0,1,     1,0,0,0},
    {0,0,0,1,     0,0,0,1,     0,0,1,0}}; *)

an = {0, 0, 0, 1,   0, 0, 0, 1,   .5, 0, .5, 0};
annuc = Total[an.nuchyd, 2]

0.461828


(*
 p=
   {{0,0,1,0,     0,0,1,0,     1,0,0,0},
    {0,0,1,0,     0,0,1,0,     0,1,0,0},
    {0,0,1,0,     0,0,1,0,     0,0,1,0},
    {0,0,1,0,     0,0,1,0,     0,0,0,1}}; *)

ap = {0, 0, 1, 0,   0, 0, 1, 0,   .25, .25, .25, .25};
apnuc = Total[ap.nuchyd, 2]

0.68978


(* q=
   {{0,0,1,0,     0,0,0,1,     0,1,0,0},
    {0,0,1,0,     0,0,0,1,     0,0,0,1}}; *)

aq = {0, 0, 1, 0,   0, 0, 0, 1,   0, .5, 0, .5};
aqnuc = Total[aq.nuchyd, 2]

0.174144


(* r=
   {{0,0,1,0,     0,1,0,0,     1,0,0,0},
    {0,0,1,0,     0,1,0,0,     0,1,0,0},
    {0,0,1,0,     0,1,0,0,     0,0,1,0},
    {0,0,1,0,     0,1,0,0,     0,0,0,1},

    {0,0,0,1,     0,1,0,0,     0,1,0,0},
    {0,0,0,1,     0,1,0,0,     0,0,0,1}}; *)

ar = {0, 0, 4 / 6, 2 / 6,   0, 1, 0, 0,   1 / 6, 2 / 6, 1 / 6, 2 / 6};
arnuc = Total[ar.nuchyd, 2]

0.585757
```

```
(* s=
   {{1,0,0,0,     0,0,1,0,     1,0,0,0},
    {1,0,0,0,     0,0,1,0,     0,1,0,0},
    {1,0,0,0,     0,0,1,0,     0,0,1,0},
    {1,0,0,0,     0,0,1,0,     0,0,0,1},

    {0,0,0,1,     0,1,0,0,     1,0,0,0},
    {0,0,0,1,     0,1,0,0,     0,0,1,0}}; *)

as = {4 / 6, 0, 0, 2 / 6,   0, 2 / 6, 4 / 6, 0,   2 / 6, 1 / 6, 2 / 6, 1 / 6};
asnuc = Total[as.nuchyd, 2]

0.968373


(* t=
   {{0,0,0,1,     0,0,1,0,     1,0,0,0},
    {0,0,0,1,     0,0,1,0,     0,1,0,0},
    {0,0,0,1,     0,0,1,0,     0,0,1,0},
    {0,0,0,1,     0,0,1,0,     0,0,0,1}}; *)

at = {0, 0, 0, 1,   0, 0, 1, 0,   .25, .25, .25, .25};
atnuc = Total[at.nuchyd, 2]

0.846655


(* v=
   {{0,1,0,0,     1,0,0,0,     1,0,0,0},
    {0,1,0,0,     1,0,0,0,     0,1,0,0},
    {0,1,0,0,     1,0,0,0,     0,0,1,0},
    {0,1,0,0,     1,0,0,0,     0,0,0,1}}; *)

av = {0, 1, 0, 0,   1, 0, 0, 0,   .25, .25, .25, .25};
avnuc = Total[av.nuchyd, 2]

1.9604


(* w=
   {{1,0,0,0,     0,1,0,0,     0,1,0,0}}; *)

aw = {1, 0, 0, 0,   0, 1, 0, 0,   0, 1, 0, 0};
awnuc = Total[aw.nuchyd, 2]

0.859942


(* (*x=
    {{1,0,0,0,     0,0,0,1,     0,0,0,1},
     {1,0,0,0,     0,0,0,1,     0,1,0,0},
     {1,0,0,0,     0,1,0,0,     0,0,0,1}}; *)

ax={1,0,0,0,    0, 1/3,0,2/3,     0,1/3,0,2/3};
 axnuc=Total[ax.nuchyd,2]  *)
```

```
(* y=
   {{1,0,0,0,     0,0,0,1,     1,0,0,0},
    {1,0,0,0,     0,0,0,1,     0,0,1,0}}; *)

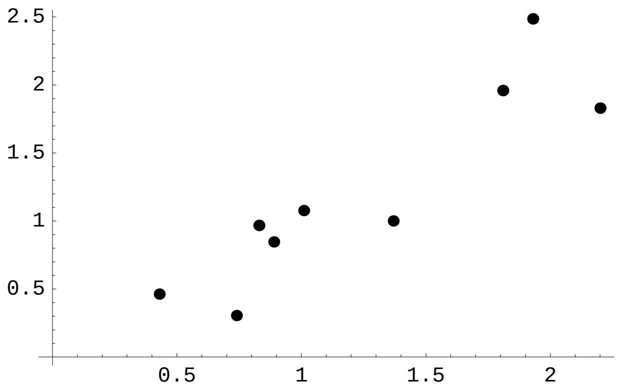
ay = {1, 0, 0, 0,   0, 0, 0, 1,   1, 0, 1, 0};
aynuc = Total[ay.nuchyd, 2]

1.07569
```

```
(* Fill empirical and SVP values for hydropathy into a 20 x 2 matrix *)

paired = {{a, aanuc}, {c, acnuc}, {d, adnuc}, {e, aenuc}, {f, afnuc}, {g, agnuc},
   {h, ahnuc}, {i, ainuc}, {k, aknuc}, {l, alnuc}, {m, amnuc}, {n, annuc}, {p, apnuc},
   {q, aqnuc}, {r, arnuc}, {s, asnuc}, {t, atnuc}, {v, avnuc}, {w, awnuc}, {y, aynuc}};

ListPlot[paired, PlotStyle → PointSize[0.02]];
FindFit[paired, intercept + slope * xaxis, {intercept, slope}, xaxis]
```




```
{intercept → 0.150414, slope → 0.860636}
```

```
(*
 Reaction Centers of Photosynthetic Bacteria (1990) Michel-Beyerle M.ed.pp.209-218,
 Springer-Verlag Berlin.  Genetic Coding Algorithms for
   Engineering Membrane Proteins.  Yang M.M.,Coleman,W.J.,& Youvan,
 D.C.Massachusetts Institute of Technology,Department of Chemistry,
 Cambridge 02139.  Abstract available at
   http://www.kairos-
   scientific.com/searchable/abstracts/Yang1990.htm and quoted here:

     A solution to the problem of relating the
      physicochemical properties of the amino acids to their codon
      sequences has been achieved by treating the genetic code as a
      system of linear equations and applying the numerical method,
 Singular Value Decomposition (SVD). For example,
 hydropathy and molar volume,
 which are important deteminants
  of protein structure and function,
 can be quantitatively related to the nucleotide sequence.The 20 hydropathy
   values of the amino acid residues were remapped to 12 nucleotide-
  determined values which, in turn,were used to predict structural
  aspects the photosynthetic reaction center protein,
 without DNA→protein translation.
 *)
```