12.1a

energy gain per unit effort — Avg profitability

$$\frac{da_{ij}}{dt} = \sigma_i a_{ij}\underbrace{\left(e_{ij} f_{ij} X_j - \sum_{k \in n_i} a_{ik} e_{ik} f_{ik} X_k\right)}_{\text{Assumes that there is a single condition that determines foraging effort}}$$

- Physiology: how close individuals are from starvation
- Ecology: landscape heterogeneity
- Stochasticity: the likelihood of finding/acquiring foods
- life history: Risk is treated differently as a function of organismal age.

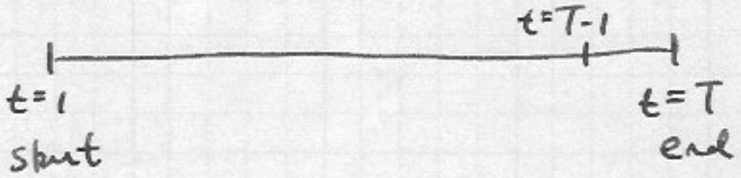
$\underbrace{\qquad\qquad}$

state-dependent foraging

stochastic (random) influences.

12.16 Canonical Equation for Activity Choice

- Consider animal during a nonbreeding season where only survival matters



- Challenge: Avoid Starvation & Predation

$X(t)$ = energetic reserves @ time t

X_c = critical level: fall below x_c and you die

X_{max} = maximum level

"Patches" ~ choices of activity (not necessarily spatial)
i ~ have individual characteristics: RISK / REWARD

Risk

$d_i = \Pr\{\text{killed in one visit to patch } i\}$

$\delta_i = \Pr\{\text{finding food in one visit to patch } i\}$

Reward

c_i = Cost of one visit to Patch i

p_i = Reward for one visit to Patch i

Patch	Risk d	Risk δ	Reward p	Reward c
1	0	1	0	1
2	0.004	0.4	3	1
3	0.02	0.6	5	1

} Tradeoffs

@ last time step, you are

- alive: $X(T) > X_c$
- dead: $X(T) \le X_c$

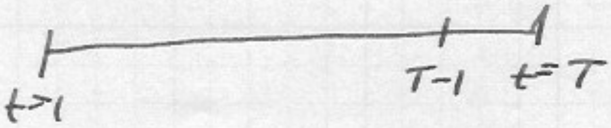
} known for $t=T$

⊛ Go backward one step @ a time $(t-1)$ to calculate

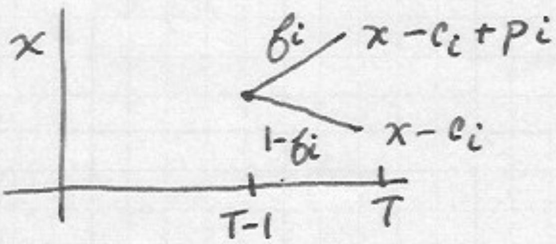
$S(x,t)$ = maximum probability of survival from $t \to T$ given $X(T) = x$

$$S(x, t=T) = \begin{cases} \varnothing & \text{if } x \le x_c \\ 1 & \text{if } x > x_c \end{cases}$$

Now for $t = T-1$



$S_i(x, T-1) = Pr\{\text{Surviving from } t=T-1 \text{ to } t=T \,|\, X(T-1)=x\}$



if activity/patch i is chosen,

- food is found: new x is $x - c_i + p_i$
- food is NOT found: new x is $x - c_i$

$\boxed{\text{at patch } i\text{: Max. prob. of survival from } T-1 \text{ to } T}$

$$S_i(x, T-1) = (1-d_i)\cdot f_i \cdot S(x - c_i + p_i, T) + (1-d_i)\cdot(1-f_i)\cdot S(x - c_i, T) + d_i \cdot \varnothing$$

[We can calculate ~~this~~ for each patch i]

12.3

We calculate

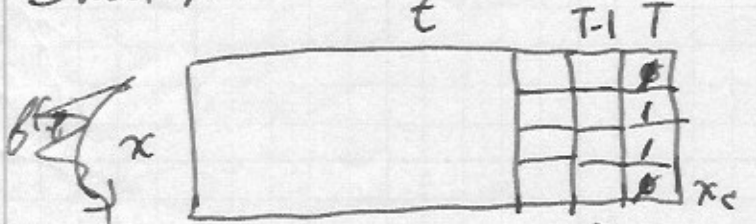
$$S_1(x, T-1)$$
$$S_2(x, T-1)$$
$$S_3(x, T-1)$$

* Max. survival prob. from T-1 to ~~t~~ T in patch/activity 1, 2, 3

We will assume the individual has evolved to maximize its survival

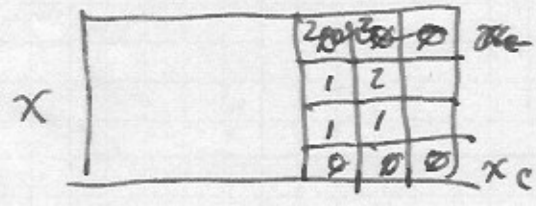
↳ $\max_i \left(S_i(x, T-1) \right\}$ → will tell you which patch/activity to choose GIVEN ~~current~~ current
1) energetic state x
2) time T-1

S matrix



we are calculating survival probabilities for each prior timestep assuming the patch that maximizes survival is chosen.

i^* matrix



When we are done, we have computed the maximum probability of survival for previous timesteps

$$S(x,t) \text{ is } \max_i \left\{ S_i(x,t) \right\}$$

12.4

$$S(x,t) = \max_i \left\{ (1-d_i) f_i \, S(x - c_i + p_i, t+1) + (1-d_i)(1-f_i) S(x - c_i, t+1) \right\}$$

w/ boundary conditions

$S(x,t) = \emptyset$ if $x \le x_c$ and $x = x_{max}$ if $x > x_{max}$

Calculate for patches $i = 1, 2, 3$ @ $t = T-1$ for $x = 6$

given $x_c = 5$, $x_{max} = 10$

and $S(x, t=T) = \emptyset$ if $x \le x_c$, 1 if $x \geq x_c$

$$S_1(x=6, T-1) = (1-\emptyset)(1) \cdot S(6-1+\emptyset, t+1) + (1-\emptyset)(\emptyset) S(6-1, t+1)$$

$$= S(5, t+1) = S(5, T) = \emptyset$$

$$S_2(x=6, T-1) = (1-\emptyset.\emptyset\emptyset4)(\emptyset.4) S(6-1+3, t+1) + (1-\emptyset.\emptyset\emptyset4)(1-\emptyset.4) S(6-1, t+1)$$

$$= (\emptyset.39) S(8, t+1) + \emptyset = \emptyset.39$$

$$S_3(x=6, T-1) = (1-\emptyset.\emptyset2)(\emptyset.6) S(6-1+5, t+1) + (1-\emptyset.\emptyset2)(1-\emptyset.6) S(6-1, t+1)$$

$$= (\emptyset.58) S(10, t+1) + \underbrace{(\emptyset.39) S(5, t+1)}_{\emptyset}$$

$$= \emptyset.58$$

$$S(x=6, t=T-1) = \max \left\{ \overset{1}{\emptyset}, \overset{2}{\emptyset.39}, \overset{3}{\emptyset.58} \right\}$$

so given that energetic state, and that time interval, activity/patch $\underline{3}$ maximizes the Prob(surviving from $t=T-1$ to $t=T$)

12.5

The Pseudo Code

① Define Constants

$xc = 3$

$xmax = 10$

$TMAX = 20$

② Create Patch-specific vectors

~~etc~~ E[3]

P[3]

f[3] & input values

d[3]

V[3] ← final values over which we maximize

③ Create Survival matrix & Decision matrix

$$\underset{\uparrow\,x\quad\uparrow\,t}{S[10, 2\phi]} \qquad D[1\phi, \cancel{2\phi}\ \cancel{\phi\phi}\ 2\phi]$$

④ Define end condition (terminal fitness function)

$\Phi = \phi$ for $x = 1$ to $x = 3$

$= 1$ for $x = 4$ to $x = \cancel{3}1\phi$

13.1 General

$$S(x,t) = \max_i \left[(1-d_i) f_i S(x - c_i + p_i, t+1) + (1-d_i)(1-f_i) S(x - c_i, t+1) \right.$$

$$S(x,T) = \Omega(x) = \frac{x - x_c}{x - x_c + \bar{x}}$$

Matrix

$S(x,t)$: Survival from t to $t=T$ ~~given~~ @ energy level x

$i^*(x,t)$: Survival-maximizing decision @ t, x

$S(x,t) \leq S(x,t+1)$

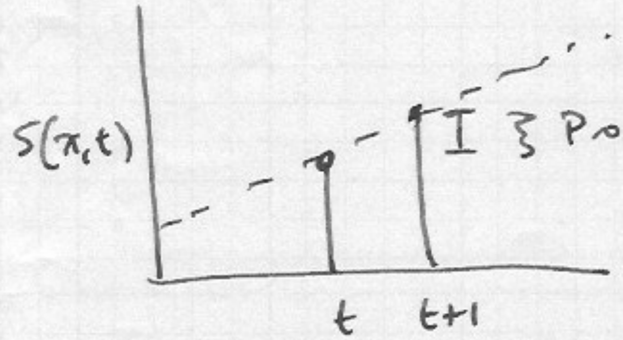
What is the probability of dying in timestep t?

$1 - S(x,t+1) \sim$ ~~Surviving~~ Dying ~~from~~ btw $t+1 \to T$

$1 - S(x,t) \sim$ ~~Existing~~ Dying ~~from~~ btw $t \to T$

~~$1 - S(x,t+1) - (1 - S(x,t))$~~

$$(1 - S(x,t)) - (1 - S(x,t+1)) = \underbrace{S(x,t+1) - S(x,t)}$$



Behavioral Predictions via Monte-Carlo Forward Simulations

- Many inds in computer simulation $= N$

$X_n(t)$ = state of nth individual @ start of period t

where $x_c \leq x_n(1) \leq x_{max}$

13.2

$X_n(t) \Rightarrow i^*(x_n(t), t)$

Possible states @ $t = t+1$

$$x_n(t+1) = \begin{cases} \cancel{x_c \text{ w/prob } d_{i^*}(x_n,t)} \\ x_c \text{ w/prob } d_{i^*}(x_n,t) + \underbrace{(1-d_{i^*}(x_n,t))(1-f_{i^*}(x_n,t))}_{\text{and } \{x_n(t) - c_{i^*}(x_n,t) \le x_c\}} \\ x_n(t) + y_{i^*}(x_n,t) - c_{i^*}(x_n,t) \\ \quad \text{w/prob. } (1-d_{i^*}(x_n,t))(f_{i^*}(x_n,t)) \\ x_n(t) - c_{i^*}(x_n,t) \\ \quad \text{w/prob } (1-d_{i^*}(x_n,t))(1-f_{i^*}(x_n,t)) \\ \quad \text{and } \{x_n(t) - c_{i^*}(x_n,t) > x_c\} \end{cases}$$

-Determine dead/alive

$U \sim$ runif

if $U_d < d_i$, then dead

if $U_d > d_i$, then alive and we want to know probability of finding food

if $U_f < f_i$, then find food

$> f_i$, then you don't

13.3

Pseudo Code

⓪ Solve SDP, get $i^*(x,t)$

① Put in all parameters incl. $X_n(t)$ & dims.

② Generate initial conditions for individuals

③ Go forward in time until $t=T$

@ each t, cycle over all individuals

if $x_n(t)=x_c$ set $x_n(t+1)=x_c$

if $x_n(t)>x_c$ draw $\mho_d$ and $\mho_f$

if $\mho_d \le d_{i^*}(x_n(t),t)$ then $x_n(t+1)=x_c$

if $\mho_d > d_{i^*}(x_n(t),t)$ & $\mho_f \le f_{i^*}(x_n(t),t)$

then $x_n(t+1)=\min\left[x_{max}, x_n(t)+ p_{i^*}() - c_{i^*}()\right.$

if $\mho_d > d_{i^*}()$ & $\mho_f > f_{i^*}()$

then $x_n(t+1)=\max\left[x_c, x_n(t) - c_{i^*}()\right.$

④ Summarize

⑤ Miller Time