- multi-species system
- Population dynamics of a focal species
- *S* state variables (the abundance of each species)
- At each of *t* time steps
- If deterministic, all of the abundances at *t*+1 are fully determined by the abundances at *t*
- Can write this as

$$\bar{y}_{t+1} = F(\bar{y}_t)$$

- could assume some parametric shape, e.g., logistic growth

$$N_1(t+1) = r_1 N_1(t)[1 - N_1(t)/K_1 - \alpha_{1,2} N_2(t)]$$
$$N_2(t+1) = r_2 N_2(t)[1 - N_2(t)/K_2 - \alpha_{2,1} N_1(t)]$$

- with parameters r1, r2, k1, k2, alpha12, and alpha21
- But we might get the form wrong
- And there are typically way more than two species that are important so the number of parameters is going to get large quickly

EDM

- Model arbitrarily complex F
- Empirical dynamic modeling
- SHOW VIDEO
- Can capture the complexity of a multiple species/state system in a single species/state time-series
- Does this based on Taken's Theorem
- Reconstruct a shadow of the real system from single time-series
- In other words, instead of relying on:

$$y_{1,t+1} = F(y_{1,t}, y_{2t}, y_{3t} \cdots y_{nt})$$

- the system dynamics can be represented as a function of a single variable and its lags:

$$y_1(t+1) = G(y_1(t), y_1(t-1), y_1(t-2) \cdots y_1(t-E))$$

- E is the embedding dimension which defines how far back in time we go
- Makes conceptual sense because if we watch a single time series from this system long enough, it should encode the information from all of the populations in what happens to the focal population

HOW DO WE DO THIS

- need to estimate G from data
- Normally do this by fitting parameters in a model
- But we don't know what G is
- Since we're focusing on prediction, don't need equation, just what will happen next
- If we knew the abundance of all of the other species we know that F should give us the abundance at the next time step
- We don't know what F is, but if we'd previously observed the system with these same abundance, then whatever happened next should also be what happens next now because that is the outcome of F

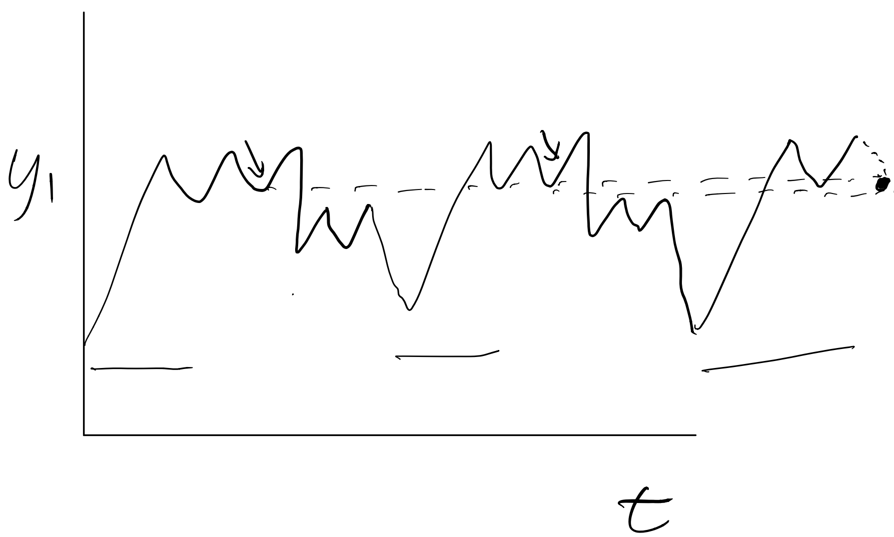
$$F(y_1 = 20, y_2 = 10) \longrightarrow y_1 = 22, y_2 = 8$$

- But we don't have all of these abundance's so we're going to rely on taken's theorem

$$G(y_t = 20, y_{t-1} = 18, y_{t-2} = 19)$$

$$\longrightarrow y_{t+1} = 22$$

- core strength and limitation of a lot of ML approaches, which is that they learn how the system has worked in the past and assume its going to work the same way in the future



y_1
t