Example of a population-synthesis code:
The Binary Stellar Evolution (BSE) code

* BSE is the fastest pop. synthesis code

* Not particularly updated (star evolution from '90s) but easiest to run

* presented in Hurley et al. 2000, 2002:
 http://adsabs.harvard.edu/abs/2000MNRAS.315..543H

 http://adsabs.harvard.edu/abs/2002MNRAS.329..897H

* STELLAR EVOLUTION through polynomial fitting formulas to results of stellar evolution codes

* core-collapse SNae through simplified recipes (NOTE: maximum black hole mass <30 Msun for these recipes)

* binary evolution includes all processes we discussed (wind mass accretion, Roche lobe overflow, common envelope, tidal evolution, gravitational wave decay)

* Download from
http://astronomy.swin.edu.au/~jhurley/

* Untar: **tar xvfz bse.tar.gz**

* Compile with makefile
    make sse (for single star evolution)
    make bse (for binary star evolution)
    make popbin (for running a set of binaries)

ADVICE: in Makefile replace
CMPLR = f77
with
CMPLR = gfortran

* Run evolution of a single binary with **./bse**

* Reads input from **binary.in**

binary.in format:

3.0 0.3 15000. 200.0 1 1 0.001 0.5

#mass of star 1 (Msun), mass of star 2 (Msun), integration time (Myr), period (days), type of star 1, type of star 2, metallicity (Z), eccentricity (from 0 to 1)

0.5 0.0 1.0 3.0 0.5

#neta (wind efficiency parameter from eq. 106 of Hurley+ 2000, Kudritzki & Reimers 1978), bwind (mass-loss enhancement param. due to tidal effects from eq. 12 of Hurley+ 2002), hewind (wind efficiency param. for Helium star mass loss), alpha (common envelope parameter), lambda (common envelope parameter)

0 1 0 1 0 1 3.0 29769

#ceflag (ceflag = 3 activates de Kool common-envelope model), tflag (tflag > 0 activates tidal circularisation), ifflag (ifflag > 0 uses WD IFMR of Hurley+ 1995, MNRAS, 272, 800), wdflag (wdflag > 0 uses modified-Mestel cooling for Wds), bhflag (bhflag > 0 allows velocity kick at BH formation), nsflag (bhflag > 0 allows velocity kick at BH formation), mxns (is the maximum NS mass mxms=1.8, nsflag=0; 3.0, nsflag=1), idum (idum is the random number seed used by the kick routine)

binary.in format:

0.05 0.01 0.02

#parameters that determine the timesteps chosen in each evolution phase:
* pts1 - MS (0.05)
* pts2 - GB, CHeB, AGB, HeGB (0.01)
* pts3 - HG, HeMS (0.02)
* as decimal fractions of the time taken in that phase.

190.0 0.125 1.0 1.5 0.001 10.0 -1.0

#
* sigma is the dispersion in the Maxwellian for the SN kick speed (190 km/s).
* beta is wind velocity factor, equation 9 of Hurley+ 2002.
* xi is the wind accretion efficiency factor (μ_W in eq. 11 of Hurley+ 2002).
* acc2 is the Bondi-Hoyle wind accretion factor (α_W in eq. 6 of Hurley+ 2002).
* epsnov is the fraction of accreted matter retained in nova eruption (0.001).
* eddfac is Eddington limit factor for mass transfer (1.0).
* gamma is the angular momentum factor for mass lost during Roche lobe overflow(-1.0).

Stellar types are indicated by numbers:

0 - deeply or fully convective low mass main sequence (MS) star
1 - Main Sequence star (>0.7 Msun)
2 - Hertzsprung Gap
3 - First Giant Branch
4 - Core Helium Burning
5 - First Asymptotic Giant Branch
6 - Second Asymptotic Giant Branch
7 - Main Sequence Naked Helium star
8 - Hertzsprung Gap Naked Helium star
9 - Giant Branch Naked Helium star
10 - Helium White Dwarf
11 - Carbon/Oxygen White Dwarf
12 - Oxygen/Neon White Dwarf
13 - Neutron Star
14 - Black Hole
15 - Massless Supernova

The output is binary.dat

col. 1 = Time T (Myr)
col. 2 = Type star 1 at time T
col. 3 = Type star 2 at time T
col. 4 = mass of star 1 at time T (Msun)
col. 5 = mass of star 2 at time T (Msun)
col. 6 = mass of the core of star 1 at time T (Msun)
col. 7 = mass of the core of star 2 at time T (Msun)
col. 8 = log10 of the radius of star 1 at time T (Rsun)
col. 9 = log10 of the radius of star 2 at time T (Rsun)
col.10 = radius of star 1/ Roche lobe of star 1 at time T
col.11 = radius of star 2/ Roche lobe of star 2 at time T
col.12 = log10 of the luminosity of star 1 at time T (Lsun)
col.13 = log10 of the luminosity of star 2 at time T (Lsun)
col.14 = spin of star 1 at time T
col.15 = spin of star 2 at time T
col.16 = mass loss (or accretion) of star 1 at time T (Msun/yr)
col.17 = mass loss (or accretion) of star 2 at time T (Msun/yr)
col.18 = binary semi-major axis at time T (AU)
col.19 = binary eccentricity at time T

To run multiple binaries: **./popbin**
reads **binaries.in**

3
#number of binaries to be simulated

3.0 0.3 200.0 0.5 0.001 15000.0
for each binary we write a line:
- col. 1: mass of star 1 (Msun)
- col. 2: mass of star 2 (Msun)
- col. 3: orbital period (days)
- col. 4: orbital eccentricity
- col. 5: metallicity
- col. 6: integration time (Myr)

2.9 0.9 8.0 0.7 0.02 15000.0
same for the second binary

7.816 4.387 1964.18453 0.0 0.02 15000.0
same for the third binary

The output of popbin is binaries.dat

Each row is a different binary

col. 1 = total integration time (Myr)
col. 2 = Final type star 1
col. 3 = Final type star 2
col. 4 = Final mass of star 1 (Msun)
col. 5 = Final mass of star 2 (Msun)
col. 6 = Final eccentricity of the binary
col. 7 = Final semi-major axis of the binary (AU)

NOW ENJOY BSE:

Run my examples and other examples you build, prepare scripts for analysis and analyse the results

HOW MANY BLACK HOLE BINARIES DO YOU FORM?

THANK YOU