The RGadget environment

A tidyverse inspired approach to model development work flow

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Shuttle Thread

The outline of the talk

- Gadget
    - Origins and technical description
- Gadget's user interface
    - Flexible model structure encaptured with setting files
- The RGadget environment:
    - Rgadget and MFDB
- Future work and concluding remarks

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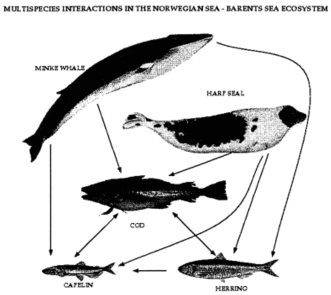
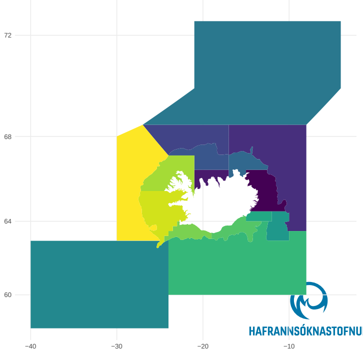
The origins of Gadget

- Gadget is an open source age and length–based, multi–species, multi-fleet, multi–area assessment modelling framework
- Gadget traces it origins to parallel modelling efforts in the North Atlantic in the early 90's
- Originally known as BORMICON, (**BOR**eal **MI**gration and **CON**sumption model) and was developed a part of a multi–species research project in the mid–1990s at the Marine Research Institute in Iceland.
- BORMICON was a conceptual descendant of MULTSPEC, a Norwegian multi-species model for the Barents sea ecosystem.
- The BORMICON code base was branched off to Norway where a single-area, single–species variant of BORMICON, FLEKSIBEST (**FLEKSI**bel **BEST**andsvurdering), was developed.
- In the early 2000s Gadget, the **G**lobally applicable **A**rea **D**isa**G**gregated **E**cosytem **T**oolbox, was created from the merger of the two forks


MULTISPECIES INTERACTIONS IN THE NORWEGIAN SEA - BARENTS SEA ECOSYSTEM
MINKE WHALE
HARP SEAL
COD
CAPELIN
HERRING



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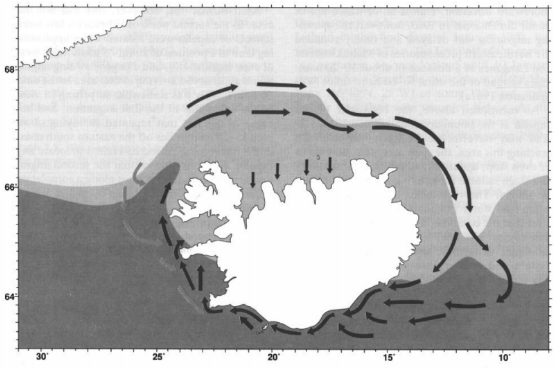
Motivation for the Framework

The original design goals of BORMICON were to (flexibly) model:

- Migrations
- Consumption of predators and fleets
- Natural mortality and growth in size
- Maturity and spawning
- External recruitment into the stock(s)
- Flexibly compare with minimaly processed data, where and when available

Where the motivating example was the cod–capelin interaction in Icelandic waters



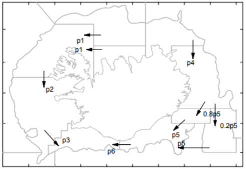


Figure 8.4.2: Migration of mature cod in January-April.

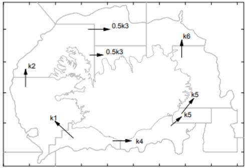


Figure 8.4.3: Migration of mature cod in June-December.

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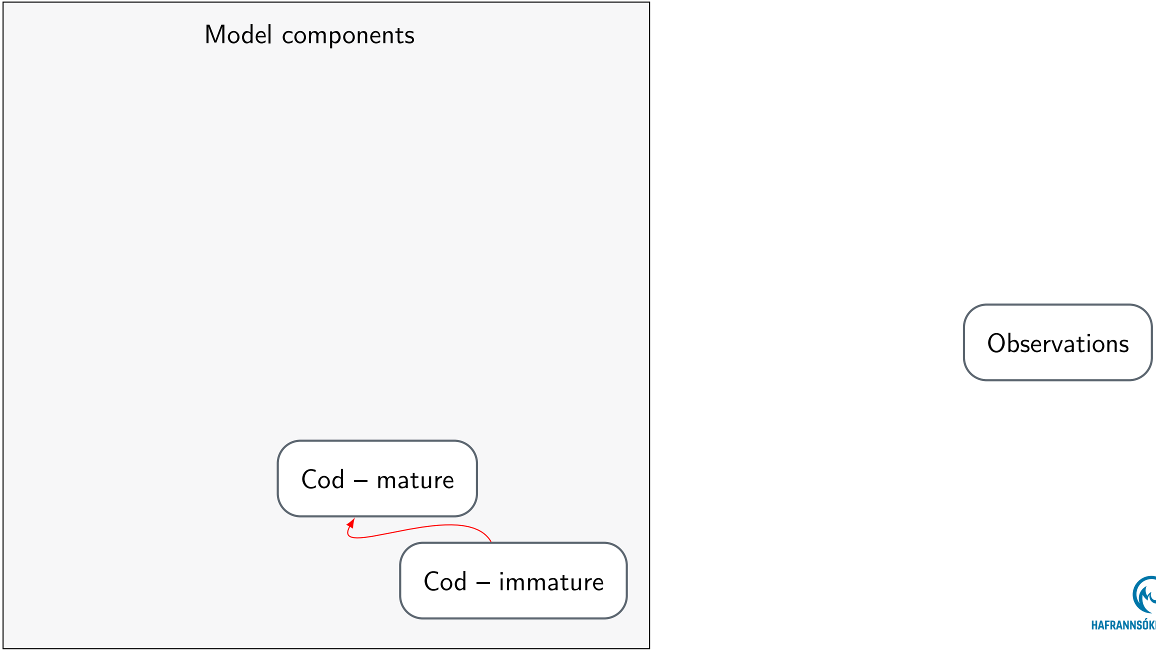
Gadget – Technical description

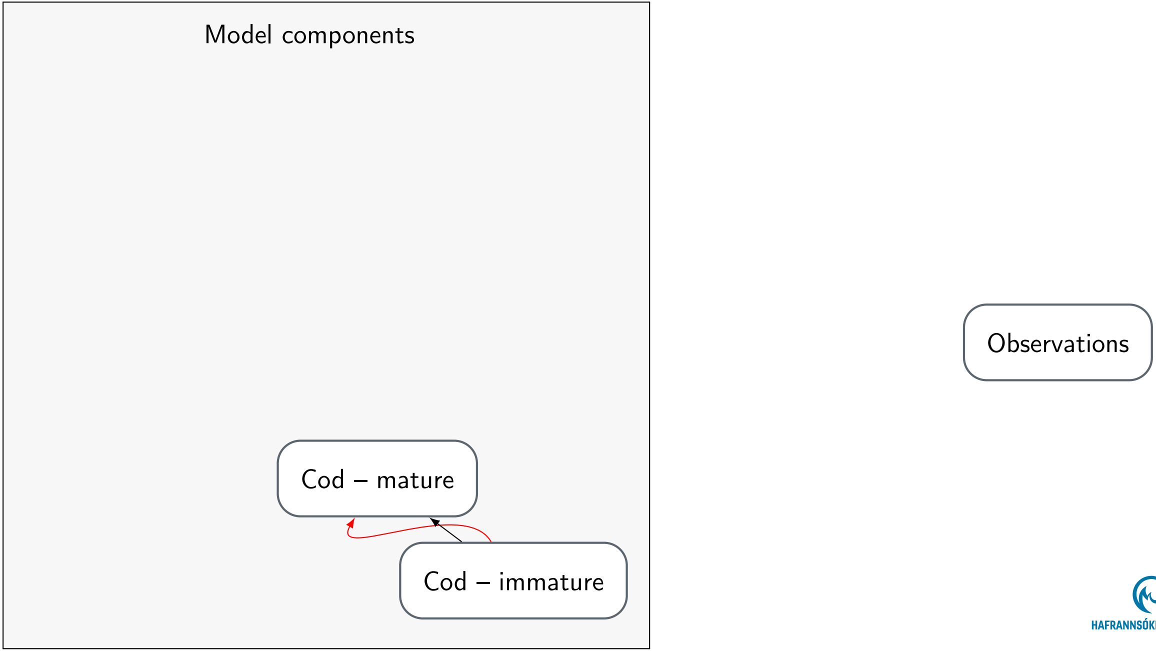
Gadget is designed as a forward simulator:

- The fundamental block in Gadget is the **substock**, an entity that is homogeneous with respect to various processes
    - For each substock the number of fish at a certain length and age is stored
    - Interaction between stock can be defined in numerous ways, such as spawning, maturation and predation.
- The substocks live in an **area**, or areas, where they optionally migrate to and from
    - Areas have various properties such as size and temperature
- Harvesting of the substocks by area and time is defined through **fleets** that fish according to either effort or total catch and use length based selection functions by stock
- The state of the ecosystem that is simulated in Gadget is observed through the substock abundance, consumption and harvest at each **timestep**
    - Length of timesteps is arbitrary and can be uneven within the year

Example model diagram



Example model diagram



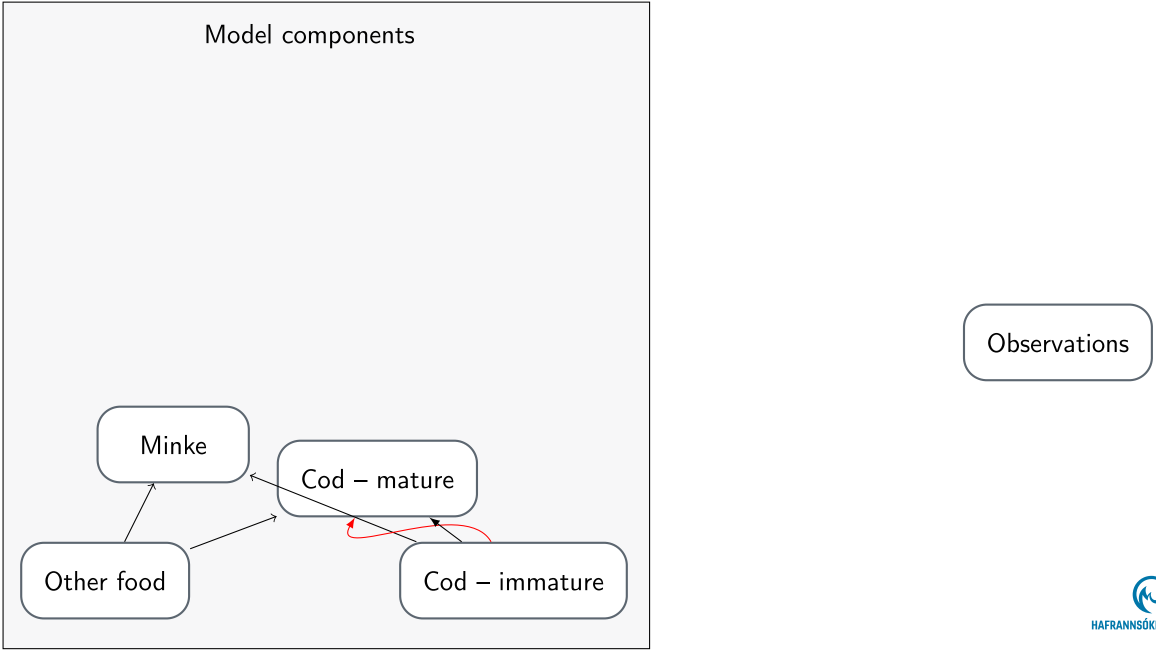
Model components

Cod – mature

Cod – immature

Observations

Example model diagram



Model components

Minke

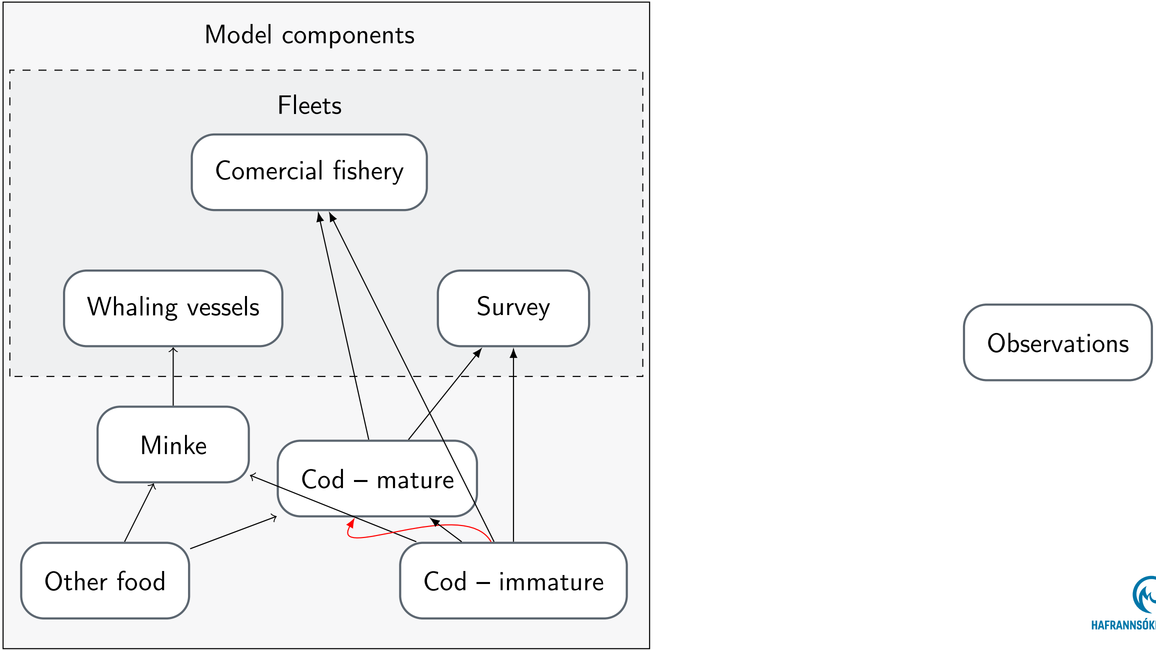
Cod – mature

Other food

Cod – immature

Observations

Example model diagram


Model components

Fleets

Comercial fishery

Whaling vessels

Survey

Observations

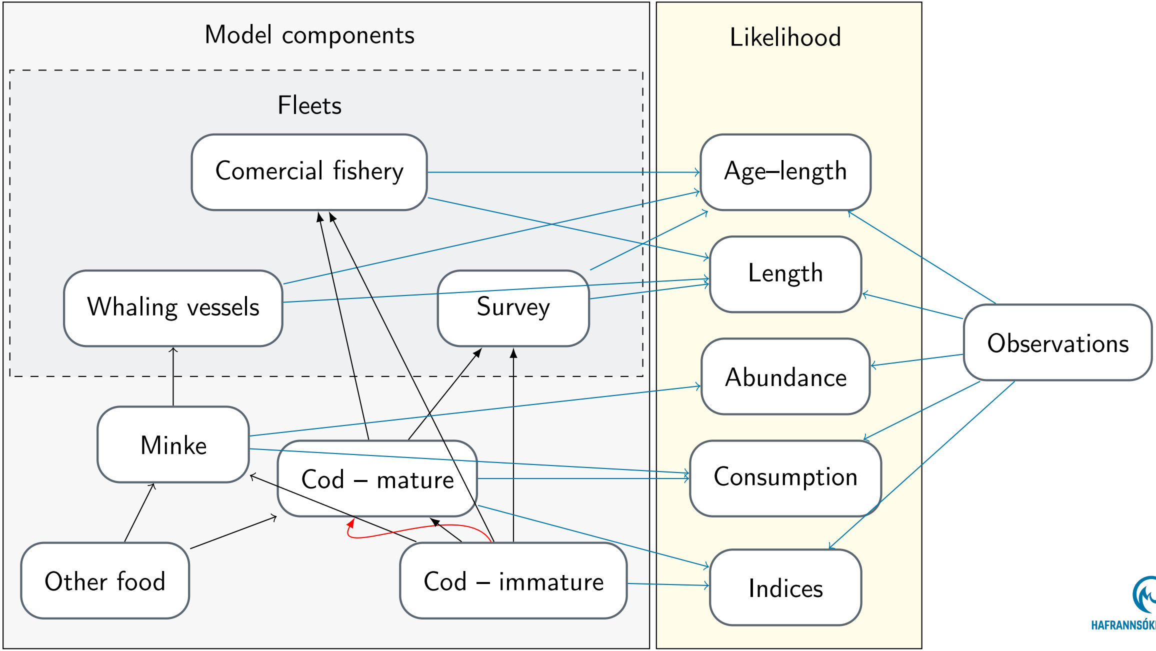
Minke

Cod – mature

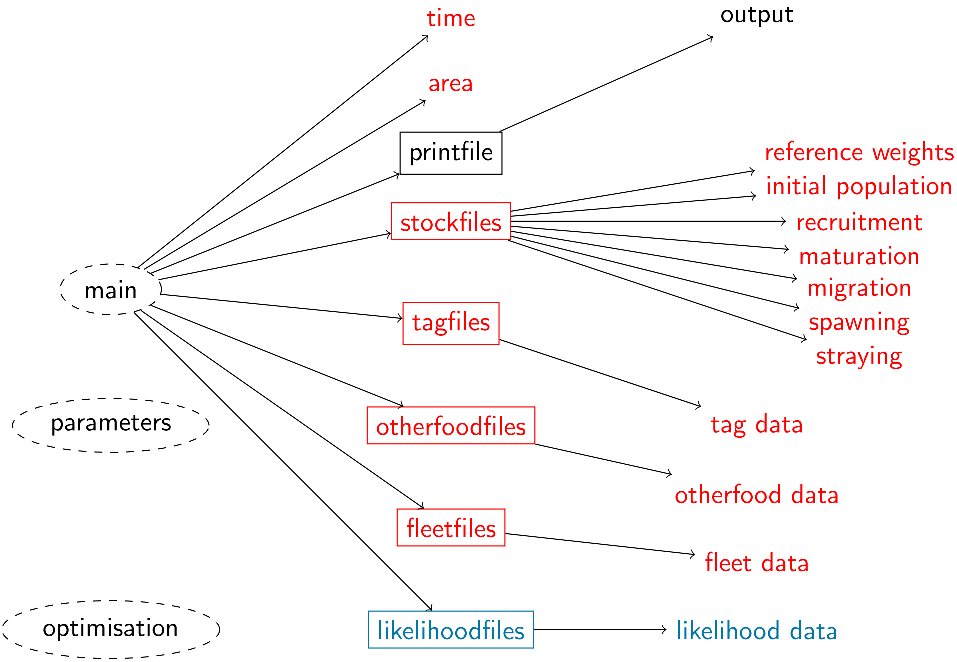
Other food

Cod – immature

Example model diagram



User interface



The stock file

```
; Generated by Rgadget 0.5
stockname  cod
livesonareas
minage
maxage
minlength
maxlength
dl
refweightfile
growthandeatlengths
doesgrow  0
naturalmortality
iseaten  0
doeseat  0
initialconditions
doesmigrate  0
doesmature  0
doesmove  0
doesrenew  0
doesspawn  0
doesstray  0
```

The stock file

```
; Generated by Rgadget 0.5
stockname  cod
livesonareas
minage
maxage
minlength
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initialconditions
doesmigrate  0
doesmature  0
doesmove  0
doesrenew  0
doesspawn  0
doesstray  0
```
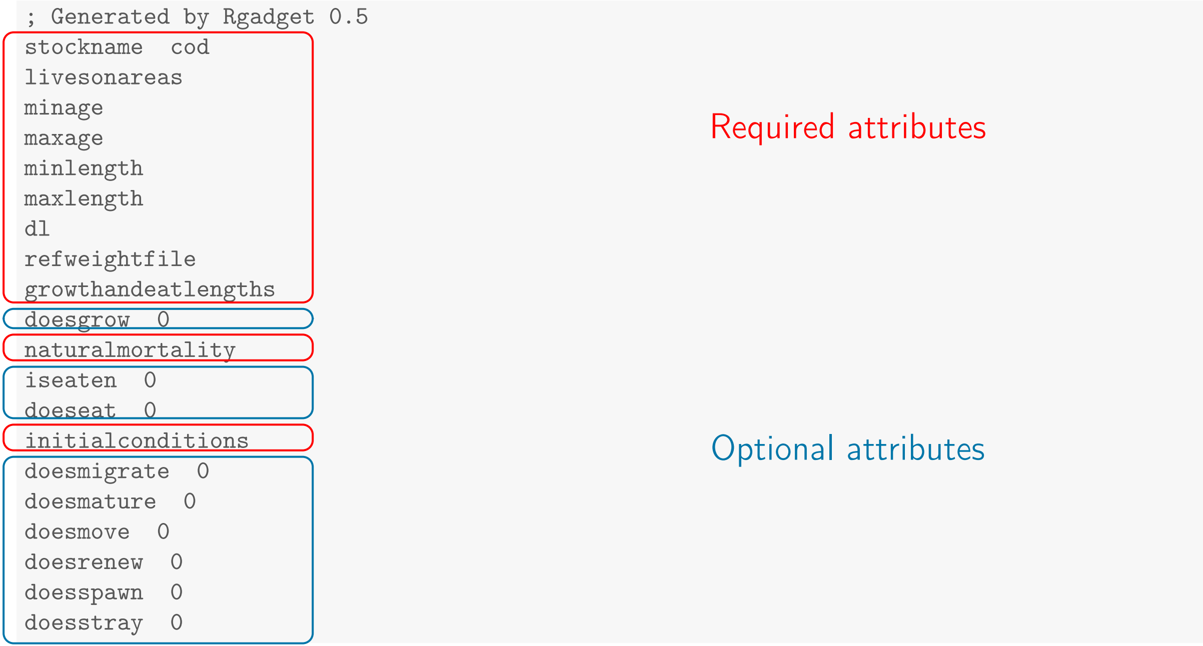

Required attributes

The stock file



```
; Generated by Rgadget 0.5
stockname  cod
livesonareas
minage
maxage
minlength
maxlength
dl
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doesgrow  0
naturalmortality
iseaten  0
doeseat  0
initialconditions
doesmigrate  0
doesmature  0
doesmove  0
doesrenew  0
doesspawn  0
doesstray  0
```

Required attributes

Optional attributes

The stock file

```
; Generated by Rgadget 0.5
stockname  cod
livesonareas
minage
maxage
minlength
maxlength
dl
refweightfile
growthandeatlengths
doesgrow  1
growthfunction  lengthvbsimple
growthparameters  #cod.Linf  (* 0.001 #cod.k)  #cod.walpha  #cod.wbeta
beta  (* 10 #cod.bbin)
maxlengthgroupgrowth  15
naturalmortality
iseaten  0
doeseat  0
initialconditions
doesmigrate  0
doesmature  0
doesmove  0
doesrenew  0
doesspawn  0
doesstray  0
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The stock file

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doesmove  0
doesrenew  0
doesspawn  0
doesstray  0
```

Optional attribute: Growth

The stock file

```
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stockname  cod
livesonareas
minage
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beta  (* 10 #cod.bbin)
maxlengthgroupgrowth  15
naturalmortality
iseaten  0
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initialconditions
doesmigrate  0
doesmature  0
doesmove  0
doesrenew  0
doesspawn  0
doesstray  0
```

Optional attribute: Growth

Gadget variables:

- #name indicates a model variable in Gadget
- Can be used instead of numbers
- Functions of model variables are entered as equations using reverse Polish notation
- Can be defined to be variable with time
- Values are controlled via the parameter file

Parameter values

```
                switch        value lower upper optimise
1             cod.Linf 1.633348e+02 1e+02   200        1
2                cod.k 9.616510e+01 4e+01   100        1
3           cod.walpha 2.275674e-06 1e-10     1        0
4            cod.wbeta 3.202005e+00 2e+00     4        0
5             cod.bbin 2.669141e+01 1e-08   100        1
6             codimm.M 1.500000e-01 1e-03     1        0
7   codimm.init.scalar 1.661737e+00 1e+00   300        1
8           cod.init.F 2.193912e-01 1e-01     1        1
9        codimm.init.3 3.663376e+02 1e-03  1000        1
10       codimm.init.4 3.772913e+02 1e-03  1000        1
11       codimm.init.5 2.820772e-01 1e-03  1000        1
12       codimm.init.6 1.000000e-03 1e-03  1000        1
13       codimm.init.7 1.000003e-03 1e-03  1000        1
14       codimm.init.8 1.000009e-03 1e-03  1000        1
15       codimm.init.9 1.000028e-03 1e-03  1000        1
```

The likelihood file

```
; Generated by Rgadget 0.5
;
[component]
name  ldist.surv
weight  1
type  catchdistribution
datafile  Data/catchdistribution.ldist.surv.sumofsquares
function  sumofsquares
aggregationlevel  0
overconsumption  0
epsilon  10
areaaggfile  Aggfiles/catchdistribution.ldist.surv.area.agg
ageaggfile  Aggfiles/catchdistribution.ldist.surv.age.agg
lenaggfile  Aggfiles/catchdistribution.ldist.surv.len.agg
fleetnames  surv
stocknames  cod
;
[component]
...
```

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; Generated by Rgadget 0.5
;
[component]
name  ldist.surv
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datafile  Data/catchdistribution.ldist.surv.sumofsquares
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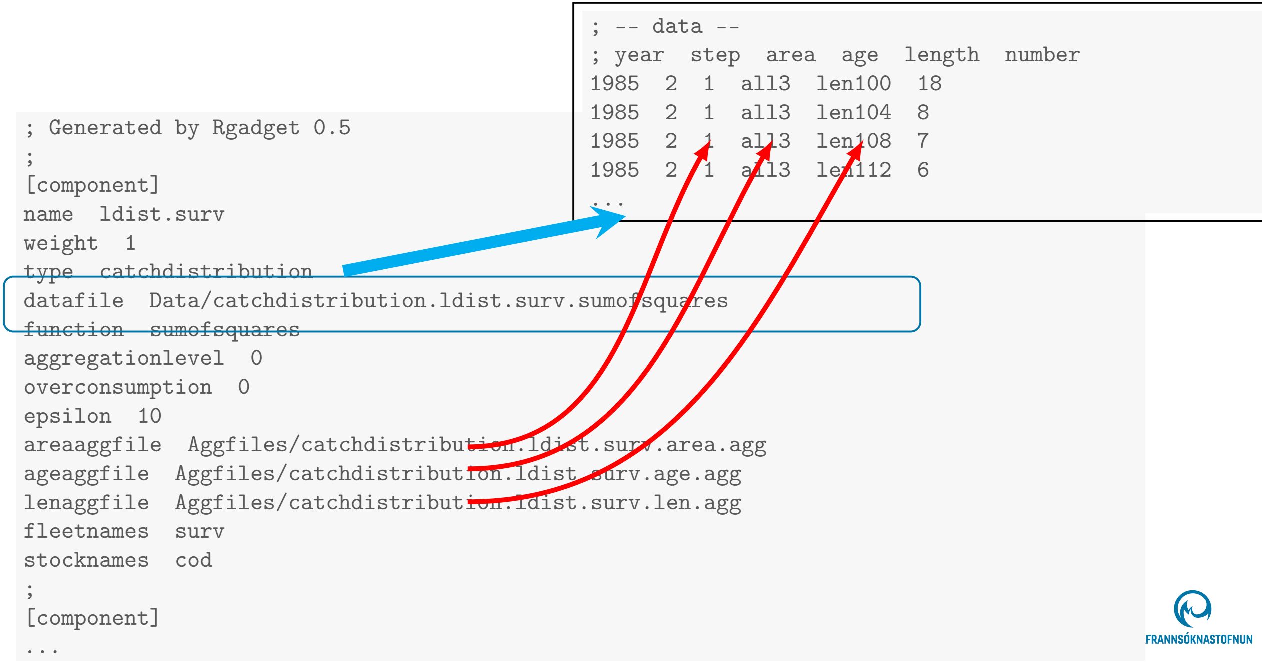
areaaggfile  Aggfiles/catchdistribution.ldist.surv.area.agg
ageaggfile  Aggfiles/catchdistribution.ldist.surv.age.agg
lenaggfile  Aggfiles/catchdistribution.ldist.surv.len.agg
fleetnames  surv
stocknames  cod
;
[component]
...
```

```
; -- data --
; year  step  area  age  length  number
1985  2  1  all3  len100  18
1985  2  1  all3  len104  8
1985  2  1  all3  len108  7
1985  2  1  all3  len112  6
...
```

The likelihood file



```
; -- data --
; year  step  area  age  length  number
1985  2  1  all3  len100  18
1985  2  1  all3  len104  8
1985  2  1  all3  len108  7
1985  2  1  all3  len112  6
...
```

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ageaggfile  Aggfiles/catchdistribution.ldist.surv.age.agg
lenaggfile  Aggfiles/catchdistribution.ldist.surv.len.agg
fleetnames  surv
stocknames  cod
;
[component]
...
```

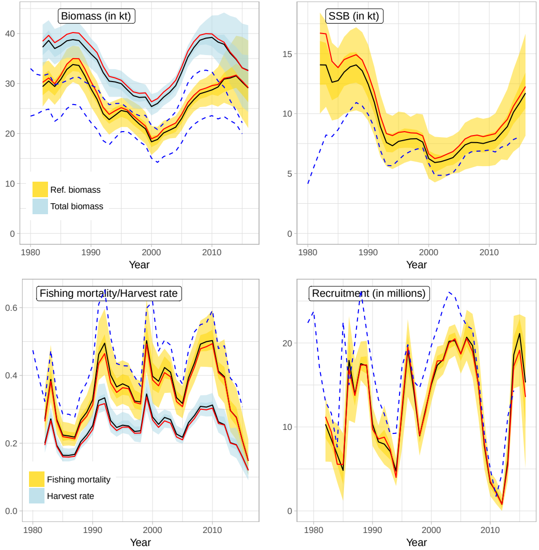
The likelihood file

```
len4   4   8
len8   8   12
len12   12   16
len16   16   20
len20   20   24
...
```

```
; Generated by Rgadget 0.5
;
[component]
name  ldist.surv
weight  1
type  catchdistribution
datafile  Data/catchdistribution.ldist.surv.sumofsquares
function  sumofsquares
aggregationlevel  0
overconsumption  0
epsilon  10
areaaggfile  Aggfiles/catchdistribution.ldist.surv.area.agg
ageaggfile  Aggfiles/catchdistribution.ldist.surv.age.agg
lenaggfile  Aggfiles/catchdistribution.ldist.surv.len.agg
fleetnames  surv
stocknames  cod
;
[component]
...
```

The problem

- Building the model by "hand"requires a lot of manual labour
    - People often resort to copy/pasting files between models
    - Model errors are not easy to track as the input files may be valid
- Disparate data types and sources
    - Aggregation files can be difficult to maintain
    - Number of likelihood components typically exceeds 10
- Reproducability!!



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    - **Solution**: generate model files using scripts
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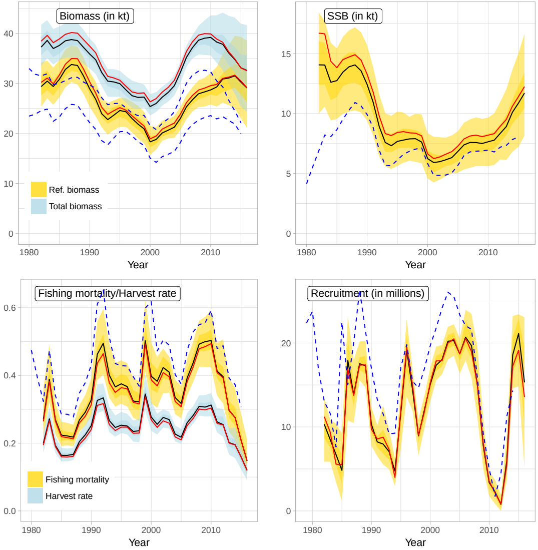
    - Aggregation files can be difficult to maintain
    - Number of likelihood components typically exceeds 10
- Reproducability!!



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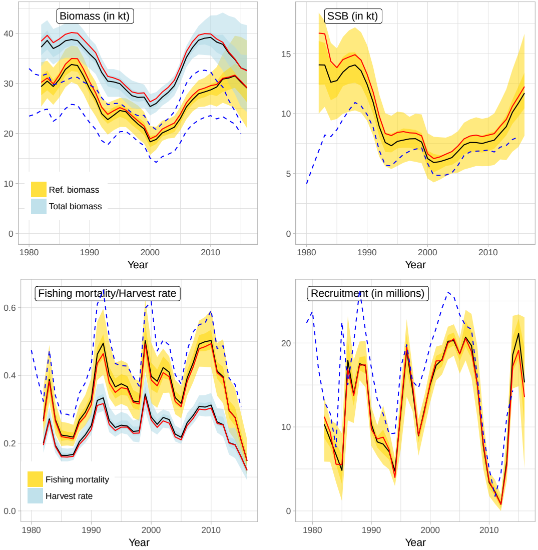
  - **Solution**: Use a database system
- Reproducability!!



The problem

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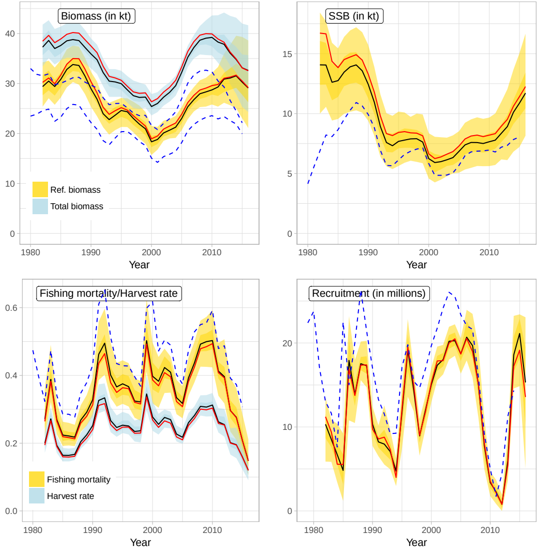
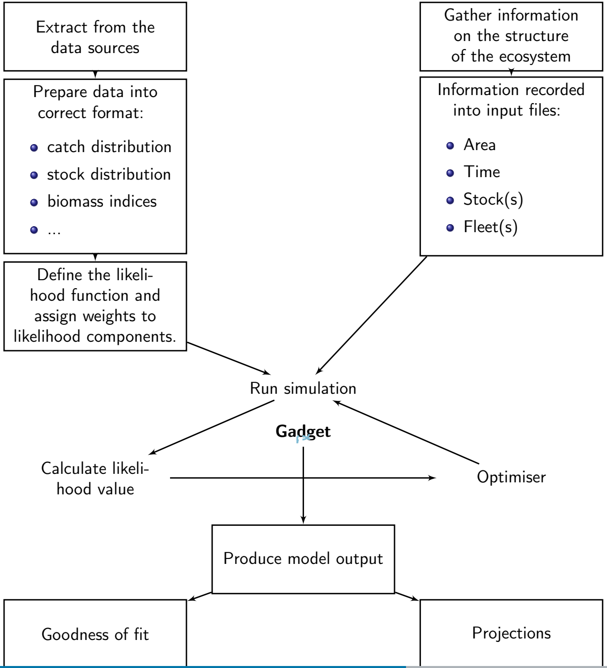
- Disparate data types and sources
    - Aggregation files can be difficult to maintain
    - Number of likelihood components typically exceeds 10
    - **Solution**: Use a database system
- Reproducability!!
    - **Solution**: store the model generating scripts in a version control system



The RGadget environment



Extract from the data sources

Prepare data into correct format:

- catch distribution
- stock distribution
- biomass indices
- ...

Define the likelihood function and assign weights to likelihood components.

Gather information on the structure of the ecosystem

Information recorded into input files:

- Area
- Time
- Stock(s)
- Fleet(s)

Run simulation

Gadget

Calculate likelihood value

Optimiser

Produce model output

Goodness of fit

Projections

The general objectives of Rgadget are to capture this entire process via R - scripts from data to TAC. This includes:

- Data formating
- Definition of relevant processes, both biological and fishing
- Fitting a model to data
- Producing diagnostics and biomass estimates
- Setup projections

Essentially we want to be able to redo the entire process either when new data are availble or significant changes have been made to the data

File manipulation

- Rgadget file manipulation routines rely on the modular Gadget file structure
  - This allows for updates of only parts of file, leaving others in place
- Files are organised into components and sub-components
- Files are linked via model directory structure
- Additional lookup files are created behind the scenes where appropriate

Fleet file:

```
[component]
linearfleet  simple_fleet
livesonareas  1
multiplicative  1
suitability
simple_stock  function  constant  0.2
amount  Data/fleet.simple_fleet.data
;
[component]
...
```

Stock file:

```
...
growthandeatlengths
doesgrow  1
growthfunction  lengthvbsimple
growthparameters  #cod.Linf  (* 0.001 #cod.k)  #cod
beta  (* 10 #cod.bbin)
maxlengthgroupgrowth  15
naturalmortality
```

Rgadget - setting up the stock file

```
library(Rgadget)

gd <- gadget.variant.dir('cod_model')

cod_stock <-
  gadgetstock('cod',gd,missingOkay = TRUE) %>%
  gadget_update('stock',
                livesonareas = 1,
                maxage = 1,
                minage = 1,
                minlength = 0,
                maxlength = 2,
                dl = 1) %>%
  gadget_update('doesgrow',0) %>%
  gadget_update('naturalmortality',0) %>%
  gadget_update('refweight',data=tibble(length=0:2,mean=0:2)) %>%
  gadget_update('initialconditions',
                normalparam = tibble(age = 1,
                                     area = 1,
                                     age.factor = 1,
                                     area.factor =1,
                                     mean = 1,
                                     stddev = .1,
                                     alpha = 1,
                                     beta = 1))
cod_stock %>%
  write.gadget.file(gd)
```

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```

Location of the model

Rgadget - setting up the stock file

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  gadget_update('doesgrow',0) %>%
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                                     area.factor =1,
                                     mean = 1,
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cod_stock %>%
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```

Location of the model

Location of the stock file

Rgadget - setting up the stock file

```r
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                maxage = 1,
                minage = 1,
                minlength = 0,
                maxlength = 2,
                dl = 1) %>%
  gadget_update('doesgrow',0) %>%
  gadget_update('naturalmortality',0) %>%
  gadget_update('refweight',data=tibble(length=0:2,mean=0:2)) %>%
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                                     area = 1,
                                     age.factor = 1,
                                     area.factor =1,
                                     mean = 1,
                                     stddev = .1,
                                     alpha = 1,
                                     beta = 1))

cod_stock %>%
  write.gadget.file(gd)
```

Location of the model

Location of the stock file

Updates the stock file, calls to gadget_update can be chained together

Example uses

Create related stocks:

```
cod_north <-
  cod_stock %>%
  gadget_update('stock',
                name = 'cod_north',
                maxage = 2,
                livesonarea = 2)
cod_north %>%
  write.gadget.file(gd)
```

Define model variants

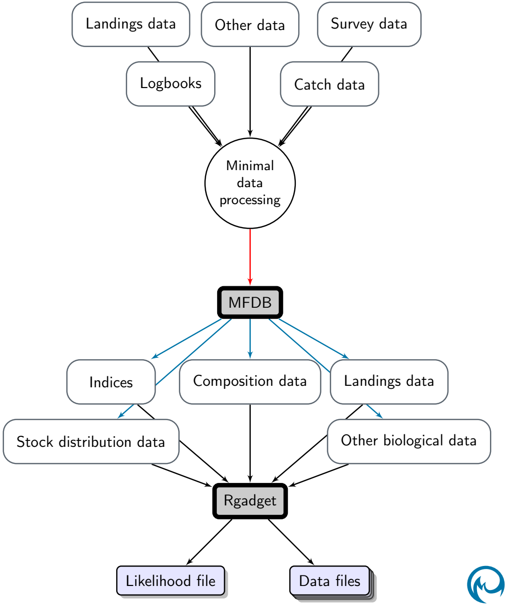
```
gd.variant <-
  gadget.variant.dir('cod_model',
                     variant_dir = 'variant_1')

## only writes files that are updated
gadgetstock('cod',gd) %>%
  gadget_update('naturalmortality',0.2) %>%
  write.gadget.file(gd.variant)
```

- Other files can similarly be edited by gadget_update
    - Including Fleet and Likelihood files
- Other files, which are simpler, such as the area and time files can be created using the gadgetfile function
- As Gadget is a forward projection model setting up projections into the future is done in the same way as for "regular"models

MFDB

The MareFrame Database (MFDB) is a R-package that has

- Automatic set-up and configuration of a PostgreSQL database on the users machine
- Functions to ingest data automatically from files or other database APIs
- Functions to transform and aggregate the data
- Functions to create input files for ecosystem modelling tools.



Preparing composition data

```
library(mfdb)
mdb <- mfdb('Iceland')

aggdata <-
  mfdb_sample_count(mdb, c('age', 'length'), list(
    age = mfdb_unaggregated(),
    length = mfdb_step_interval("len", by = 20, to = 100),
    year = 1981:2019,
    step = mfdb::mfdb_timestep_quarterly,
    area = mfdb_group("1" = unique(reitmapping$SUBDIVISION)),
    data_source = 'survey',
    species = 'COD')
```

```
gadgetlikelihood('likelihood',gd$dir,missingOkay = TRUE) %>%
  gadget_update("catchdistribution",
                name = "ldist.igfs",
                weight = 1,
                data = aggdata,
                fleetnames = c("igfs"),
                stocknames = 'cod')
```

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Preparing composition data

```r
library(mfdb)
mdb <- mfdb('Iceland')

aggdata <-
  mfdb_sample_count(mdb, c('age', 'length'), list(
    age = mfdb_unaggregated(),
    length = mfdb_step_interval("len", by = 20, to = 100),
    year = 1981:2019,
    step = mfdb::mfdb_timestep_quarterly,
    area = mfdb_group("1" = unique(reitmapping$SUBDIVISION)),
    data_source = 'survey',
    species = 'COD')
```

- Retains aggregation information from MFDB
- writes appropriate lookup information into Agg-files

```r
gadgetlikelihood('likelihood',gd$dir,missingOkay = TRUE) %>%
  gadget_update("catchdistribution",
                name = "ldist.igfs",
                weight = 1,
                data = aggdata,
                fleetnames = c("igfs"),
                stocknames = 'cod')
```

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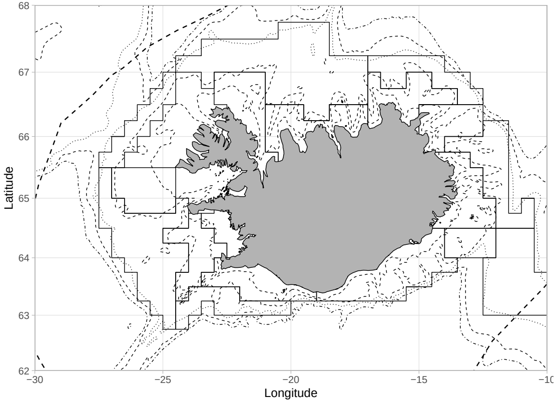
Uncertainty estimates

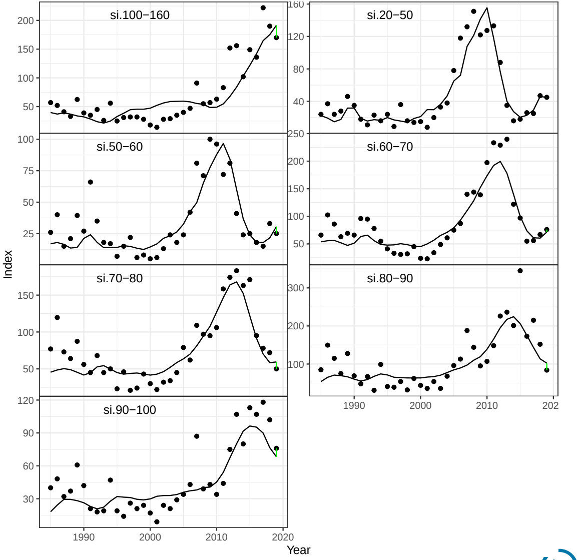
- MFDB implements a spatial bootstrap to estimated uncertainty
    - Samples recorded into MFDB are divided into spatial **divisions**
    - The divisions are treated as sampling units, that is all the samples within the division are treated as a unequal sized vector
    - New data replicates are created using resampling of the divisions, with replacement
- Model agnostic and allows comparisons between models and model platforms
- Rgadget code requires minimal modification to run a bootstrap



Additional helpers

Apart from defining the model files Rgadget has other useful tools:

- Likelihood weights can be assigned using an iterative reweighting heuristic via `gadget.iterative`
- Model diagnostics and population estimates can be collected from a model using `gadget.fit`
- Simple model projections and yield per recruit are provided via `gadget.forward` and `gadget.ypr` respectively



Next steps:

- Having the whole procedure scripted has increased the speed of model development
    - Proper processing of data is key
- We aim for tighter integration between Rgadget and Gadget:
    - Remove legacy file I/O code and pass objects directly from R
    - Text based file inputs will still be used, but read via R instead
- Automatic differention and random effects will hopefully happen
    - Just received funding from the Icelandic infrastructure fund
- More focus on the ability to define full feedback MSEs (Project on-going at the IMR in Bergen)

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Useful links

- hafro.github.io/gadget
- github.com/fishvice/gadget-models
- github.com/mareframe/mfdb
- Gadget course availble on line at heima.hafogvatn.is/∼bthe/gadget_course.html

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DST^2 EU project "Development of structurally detailed statistically testable models of marine populations"QLK5-CT1999-01609

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