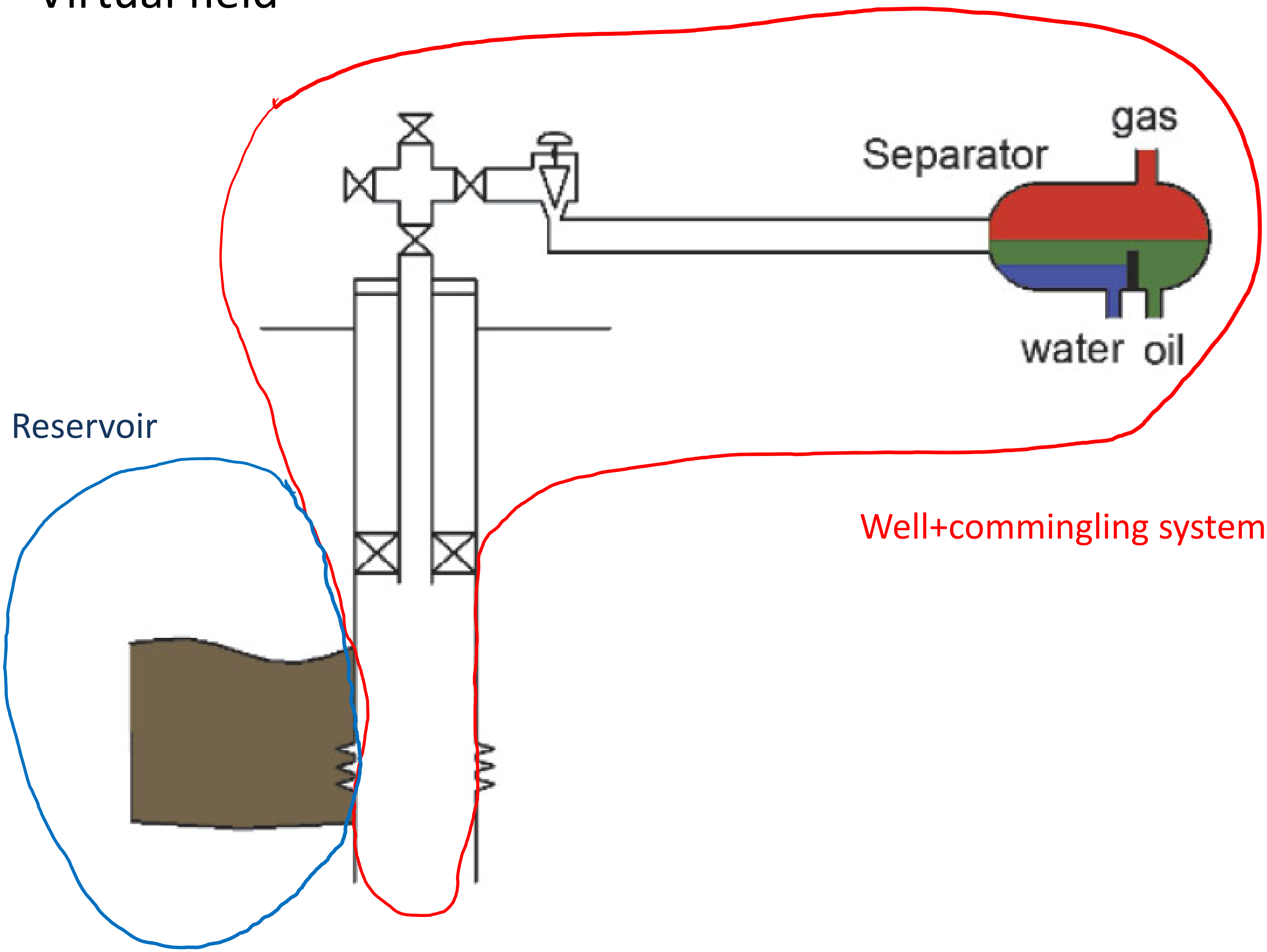
NTNU – Trondheim
Norwegian University of
Science and Technology

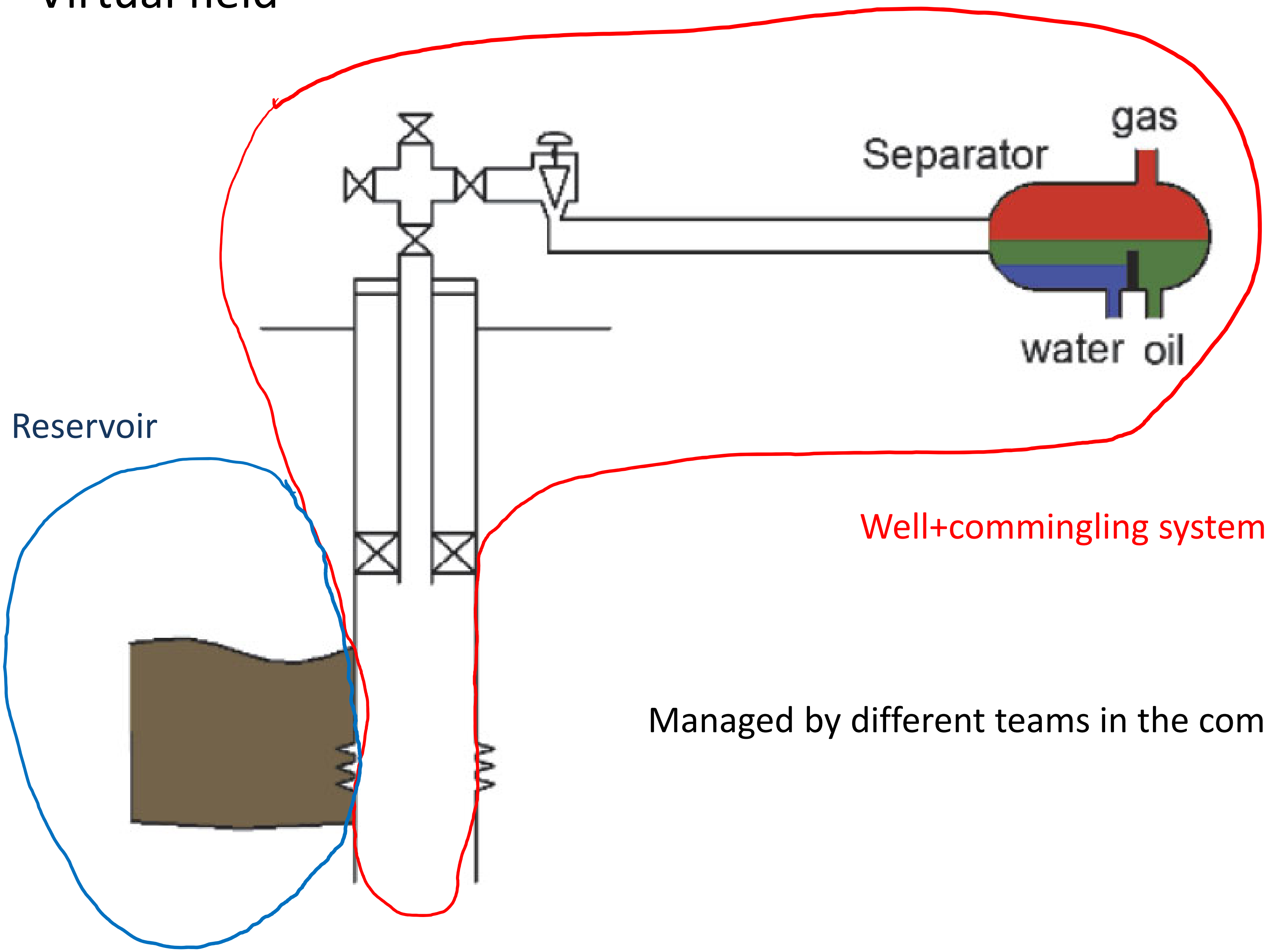
Approaches to generate production profiles

Associate Prof. Milan Stanko

Virtual field



Virtual field



Managed by different teams in the company

Alternatives to generate production profiles

-Reservoir only

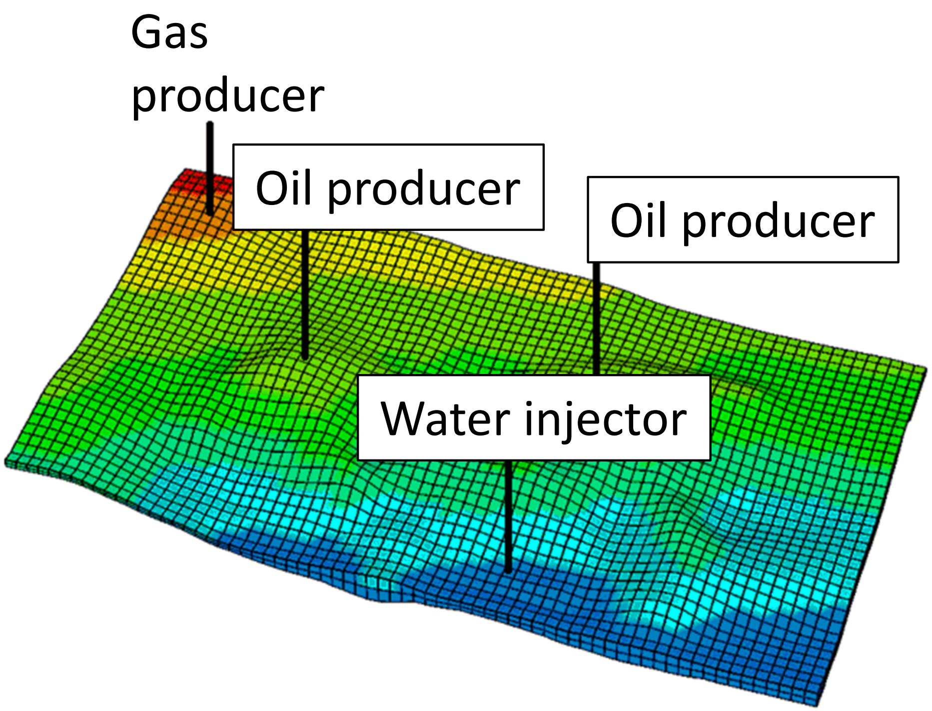
-Reservoir + network (coupled)

Reservoir model

Reservoir modeling alternatives

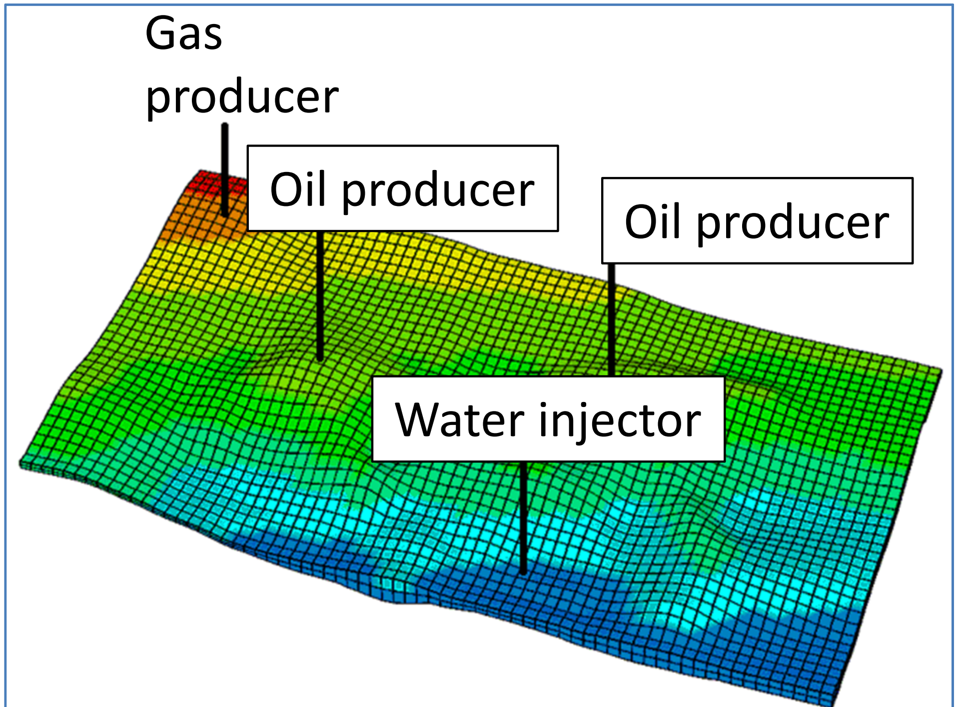
-Material balance + IPR equation (what we did in the Snowhite exercise)
-Decline (type) curves – assuming a trend of qfield versus time (e.g. exponential)
-Reservoir simulation

Reservoir model



- 3D computer representation of a petroleum reservoir
- Computes the **variation** of the pressures, saturations and other properties **with time** when fluids are retrieved from or injected into the domain
- Captures the flow in porous media in the reservoir, thermal effects, thermodynamic flashing

Reservoir model



Boundary conditions (t):

-Well target rate q_w (t) and $p_{wf\ min}$(t)

INPUT

OUTPUT

- Boundary properties p_{wf} (t), q_w (t)
- Block variables (t)
- Well variables (t)

INPUT

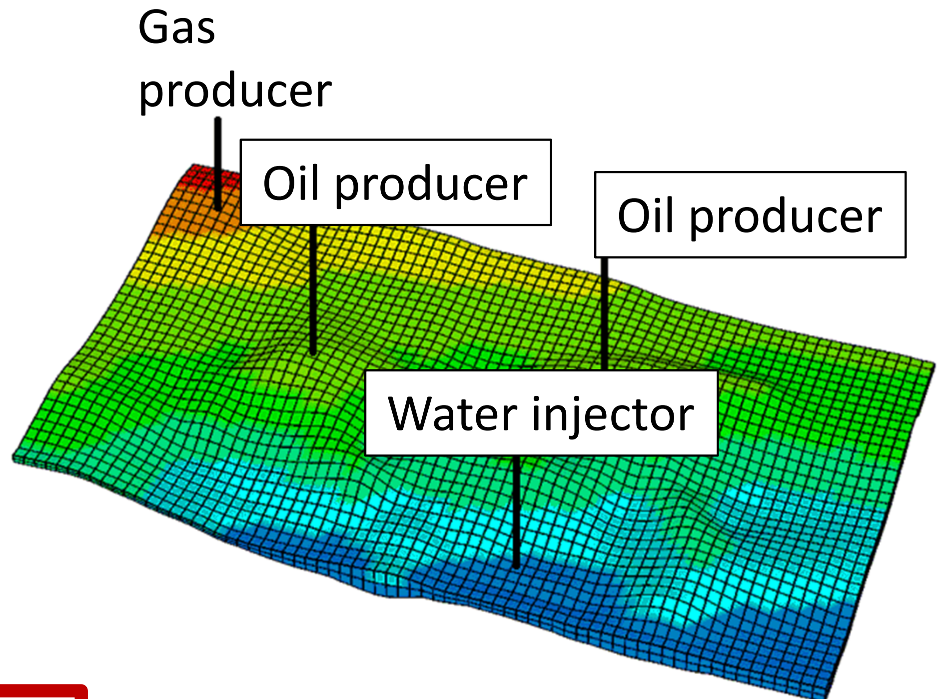
- Reservoir / system properties (Porosity, saturations, permeability, EOS, fluid composition, reservoir temperature, initial reservoir pressure)
- Well locations
- **Well status (t)**

Usually variables constant for the whole simulation time or on-off (no regulation)

Reservoir model

Boundary conditions (t):
-Well target rate q_w (t) and $p_{wf\ min}$(t)

INPUT



OUTPUT

- Boundary properties p_{wf} (t), q_w (t)
- Block variables (t)
- Well variables (t)

A GOOD GUESS(ES) FOR pwfmin is required!!

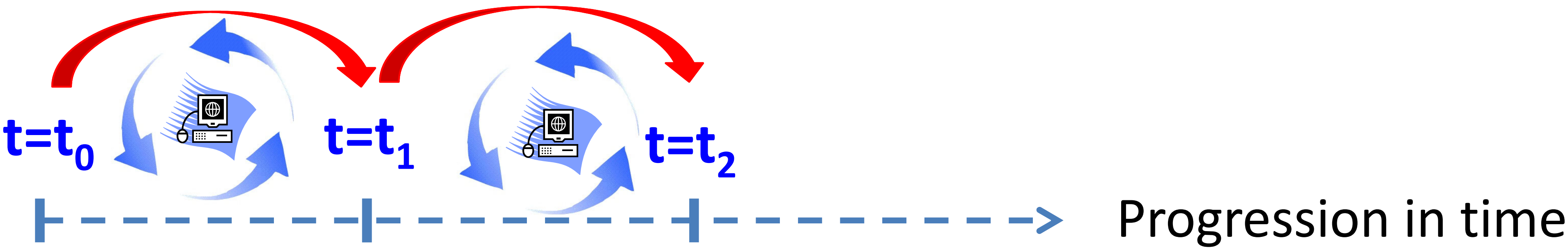
INPUT

- Reservoir / system properties (Porosity, saturations, permeability, EOS, fluid composition, reservoir temperature, initial reservoir pressure)
- Well locations
- **Well status (t)**

Usually variables constant for the whole simulation time or on-off (no regulation)

Operating mode

Reservoir model



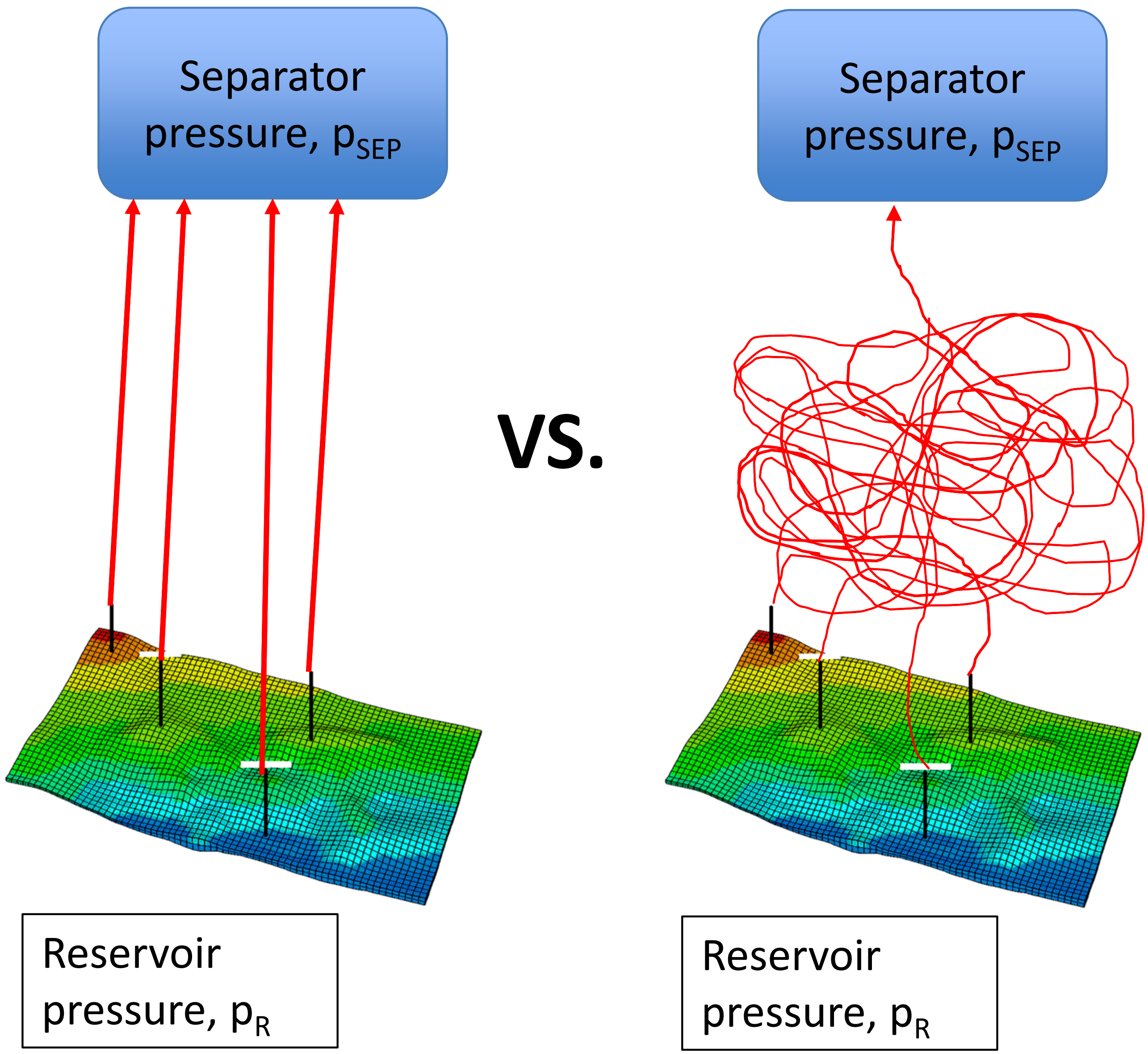
Input file - Example

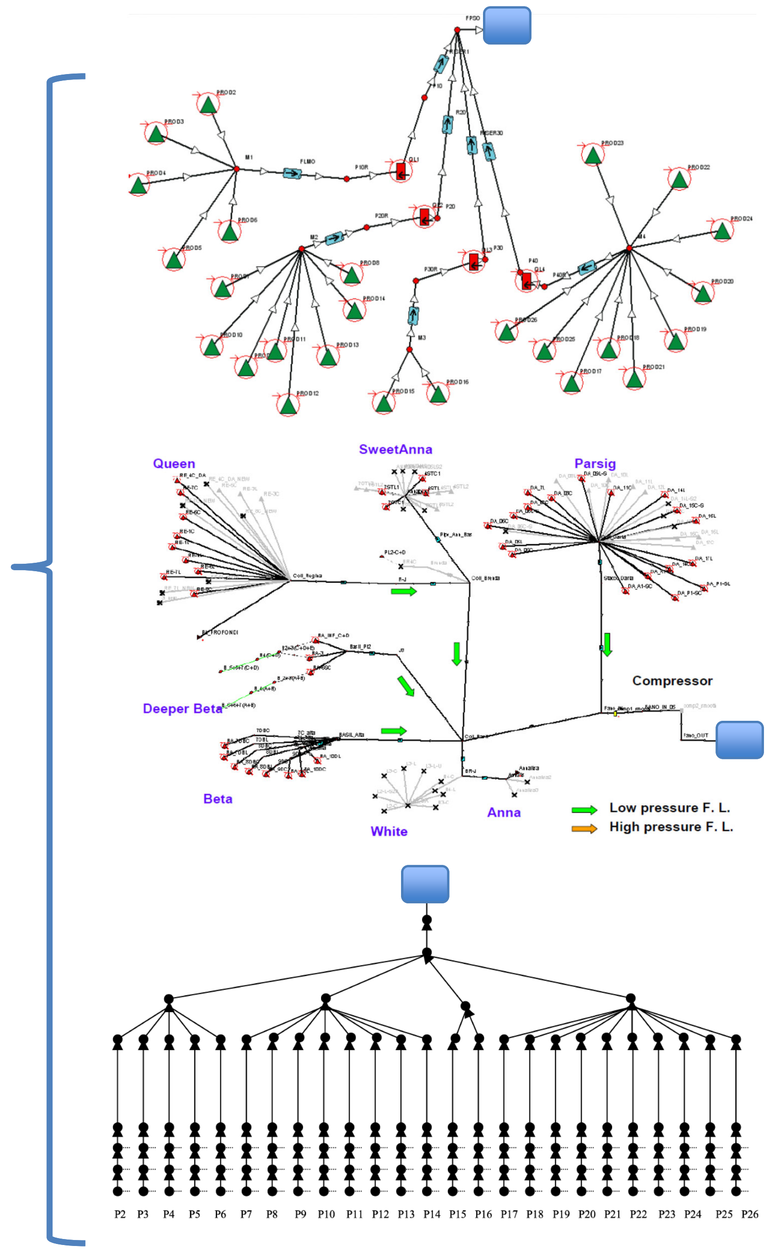
```
GRID  7 7 3
NF           ! NF is faster here than default ILU
MISC   1. 3.3E-6  62.4  .7  5E-6 4000  !  Bwi cw Denw visw cr pref

BLACKOIL 1  11  12
PRESSURES  500 800 1100 1400 1700 2000 2302 2600 2900 3300 3800 5000
RESERVOIR FLUID
    .5 .03 .07 .2 .15 .05   ! original reservoir oil
INJECTION GAS
  .77 .2 .03 3*0

C SEPARATOR  ! NOT NEEDED BECAUSE THIS IS DEFAULT
C  14.7   60.
ENDBLACKOIL

PVTEOS
  160
        CPT     PC          TC         MW       PCHOR      AC        ZCRIT
        C1    667.8000  343.0000   16.0400   71.0000  .0130000     .29
        C3    616.3000  665.7000   44.1000  151.0000  .1524000     .277
        C6    436.9000  913.4000   86.1800  271.0000  .3007000     .264
        C10   304.0000 1111.8000  142.2900  431.0000  .4885000     .257
        C15   200.0000 1270.0000  206.0000  631.0000  .6500000     .245
        C20   162.0000 1380.0000  282.0000  831.0000  .8500000     .235
BIN
           .00000  .00000  .00000  .05000  .05000
                   .00000  .00000  .00500  .00500
                           .00000  .00000  .00000
                                   .00000  .00000
                                           .00000
SWT
  .2       0.   1.       45.
  .2899  .0022  .6769  19.03
  .3778  .018   .4153  10.07
  .4667  .0607  .2178  4.9
  .5556  .1438  .0835  1.8
  .6444  .2809  .0123  .5
  .7     .4089  0.     .05
  .7333  .4855  0.     .01
  .8222  .7709  0.     0.
  .9111  1.     0.  0.
  1.     1.     0.  0.
SLT
 SGTR .2
 .2  1.   0.    30.
  .2889  .56   0.    8.
  .35    .39   0.    4.
  .3778  .35  .011   3.
  .4667  .2   .037   .8
  .5556  .1   .0878  .03
  .6444  .05  .1715  .001
  .7333  .03  .2963  .001
  .8222  .01  .4705   0.
  .9111  .001  .7023  0.
  .95    0.    .88 0.
  1.    0.   1.   0.
DELX
 7*500
DELY
 7*500
THICKNESS ZVAR
     20. 30. 50.
POROS CON
 .3
DEPTH CON
  8325.
KX ZVAR
  500. 50. 200.
KY EQUALS KX
KZ ZVAR
  50. 50. 25.
```

```
INITIAL

 SKIP

C  ** USE THIS FOR COMPOSITIONAL **
DEPTH
   8335.  2302. .5 .03 .07 .2 .15 .05   !   depth  psat  {zi}

 SKIPEND

C  ** USE THIS FOR BLACK OIL

DEPTH  PSATBP
  8335   2302.9


 PINIT 4000
 ZINIT 8400

ENDINIT

WELL
   I J K    ! PI
 INJR
    1 1 1   !  -1
 PRODR
    7 7 3   !  -1
WELLTYPE
 INJR     STBWATINJ
 PRODR    STBOIL
BHP
  INJR   4500
  PRODR  3000

C ** SKIP THIS INJGAS ENTRY FOR BLACK OIL

SKIP

INJGAS
  INJR
  .77 .2 .03 3*0

SKIPEND


RATE
 PRODR  12000

LIMITFIELD  .8333 10. 0. 0. 0. ! wcutlim gorlim wgrlim qolim qglim
                               !               (field limits)
STEPFREQ -1
WELLFREQ -1

CFL

TIMEWAG
  7300               ! proceed to 7300 days,
   INJR              ! using well INJR as injector for repeated wag cycles,
   91.25 45000  -3  !  injection of 45000 stb/d water for 91.25 days, followed by
   91.25 20000  -1  !  injection of 20000 mcf/d gas for 91.25 days

END
```

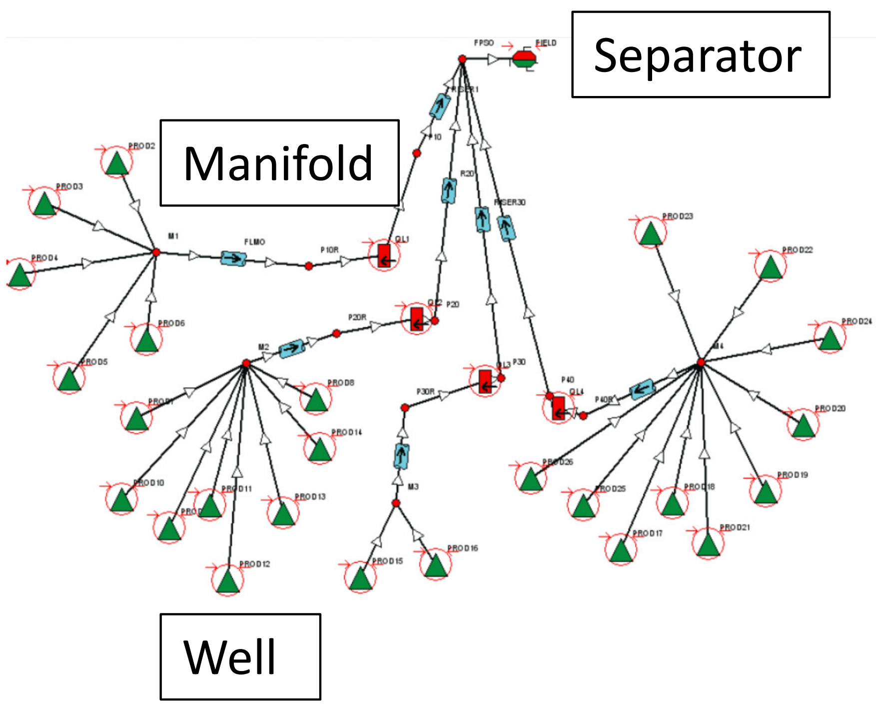
Network model

Network model characteristics





Network model

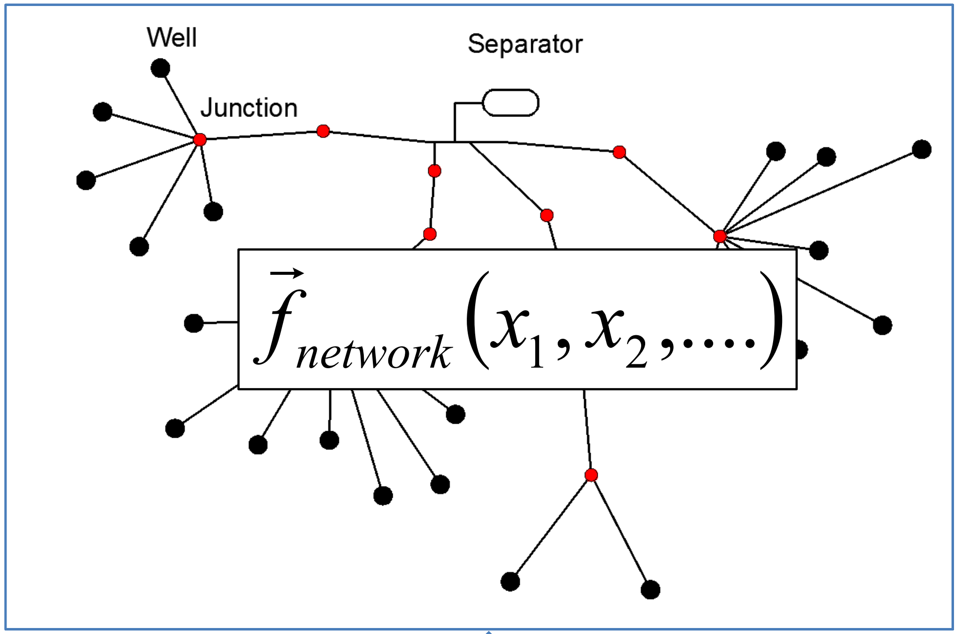


- Steady state (for a given condition in time), 1D Computer representation of a petroleum production network (wells, pipelines, equipment)
- Computes the pressure and temperature profiles in each flowline, the flow rate of each well, the conditions upstream and downstream of equipment
- Captures the single phase/multiphase flow along the production system, from the wells until the processing facilities

Network model – v1

Boundary conditions for injectors or producers:
-Well Inflow performance relationship (IPR)

INPUT



OUTPUT

- **Well flow rates**
- Pressure and temperature along the system

INPUT

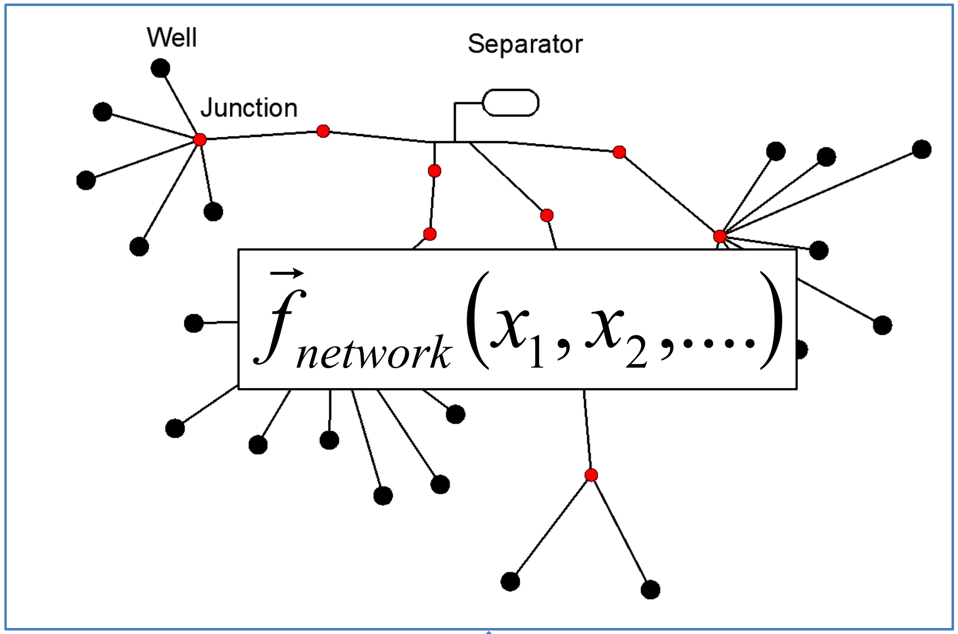
- System Properties (pipe dimensions, layout, fluid composition, EOS, separator pressure, ambient temperature)
- **Adjustable variables**: choke opening, well routing, Inflow control valves, gas lift injection rate, diluent injection rate, pump frequency, compressor.

These usually vary during the life of the field.

Network model – v1 variation (requires an "optimizer")

Boundary conditions for injectors or producers:
-Well Inflow performance relationship (IPR)
Desired well rates
-Adjustable variables will be changed to achieve well rates

INPUT



OUTPUT

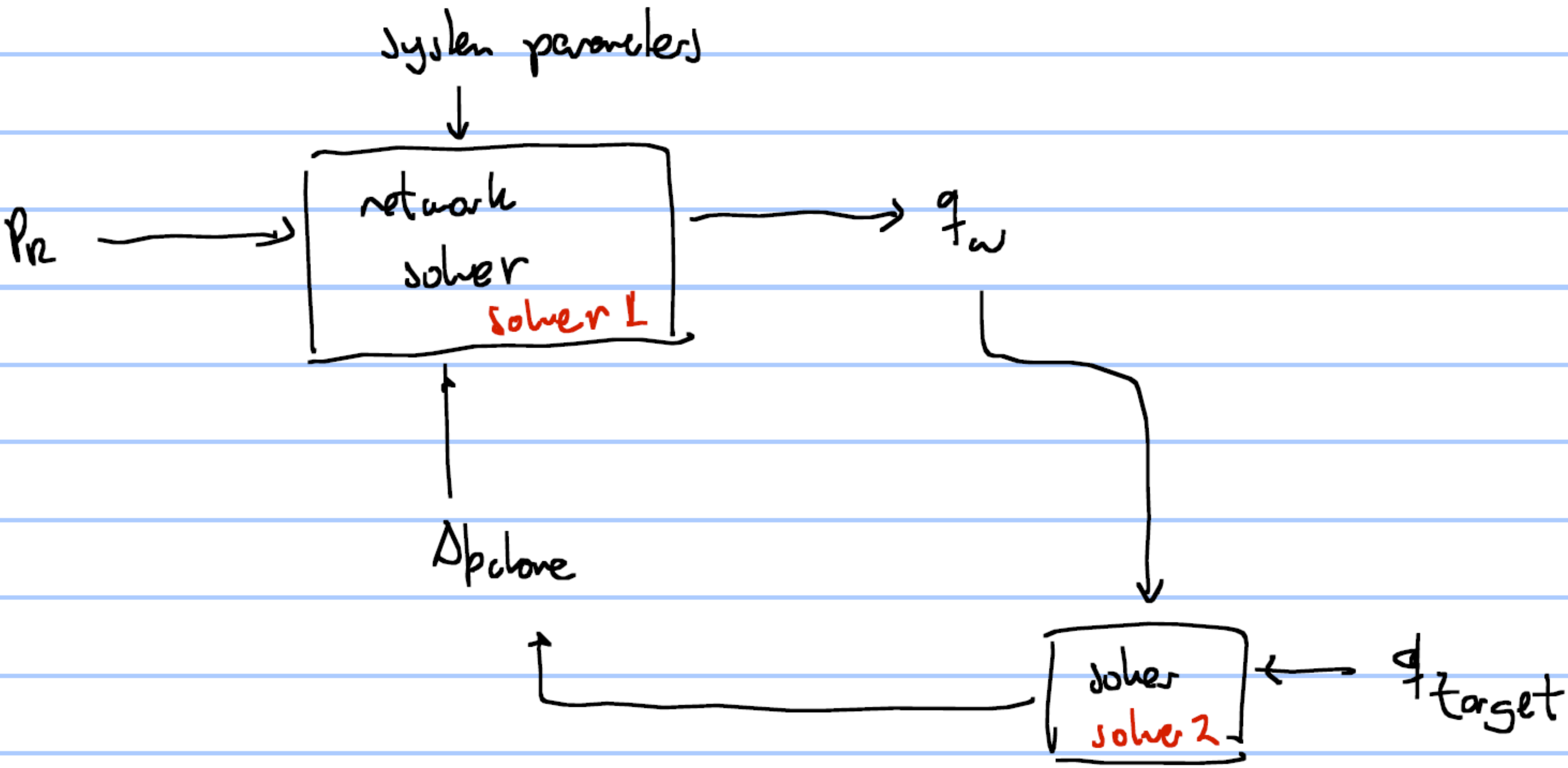
- **Well flow rates**
- Pressure and temperature along the system

INPUT

- System Properties (pipe dimensions, layout, fluid composition, EOS, separator pressure, ambient temperature)
- **Adjustable variables**: choke opening, well routing, Inflow control valves, gas lift injection rate, diluent injection rate, pump frequency, compressor.

These usually vary during the life of the field.

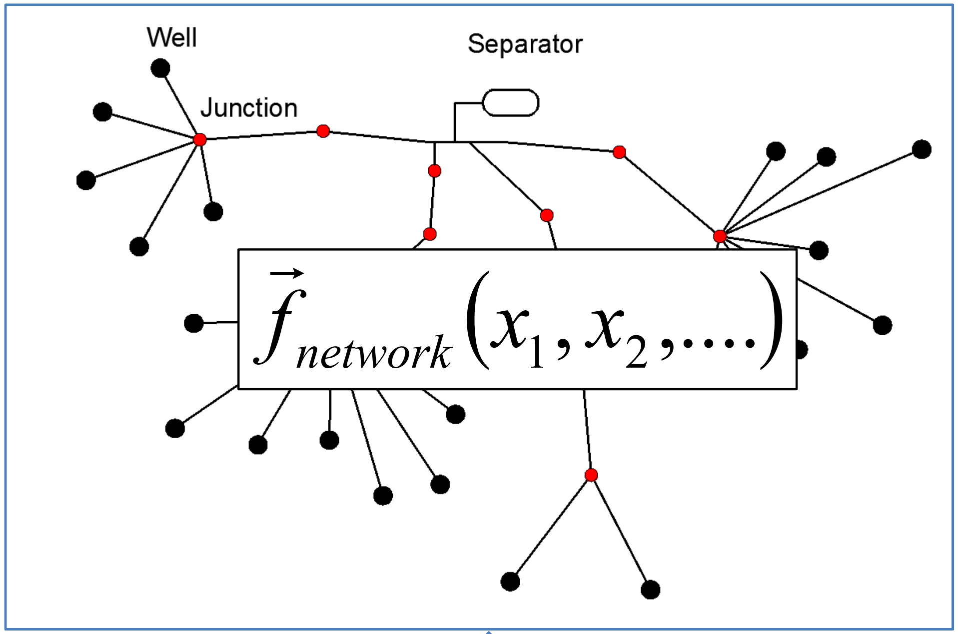
Network model – v1 variation (requires an “optimizer”)



Network model – v2

Boundary conditions for injectors or producers:
Desired well rates

INPUT



OUTPUT

- Pressure and temperature along the system
- Pressure at the boundaries

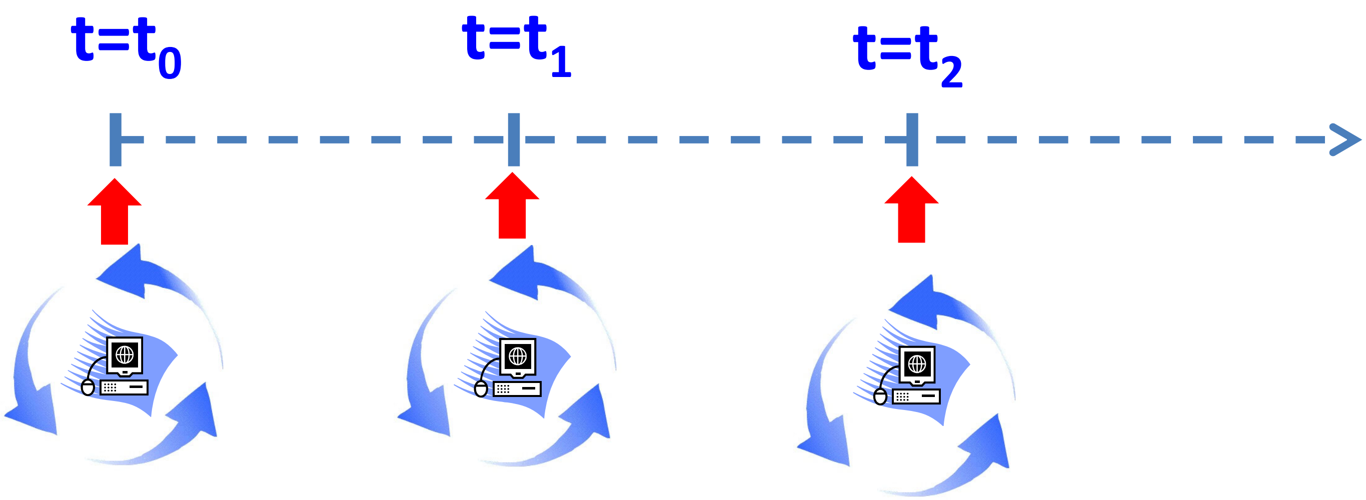
INPUT

- System Properties (pipe dimensions, layout, fluid composition, EOS, separator pressure, ambient temperature)
- **Adjustable variables**: choke opening, well routing, Inflow control valves, gas lift injection rate, diluent injection rate, pump frequency, compressor.

These usually vary during the life of the field.

Operating mode

Network model



For a given time step

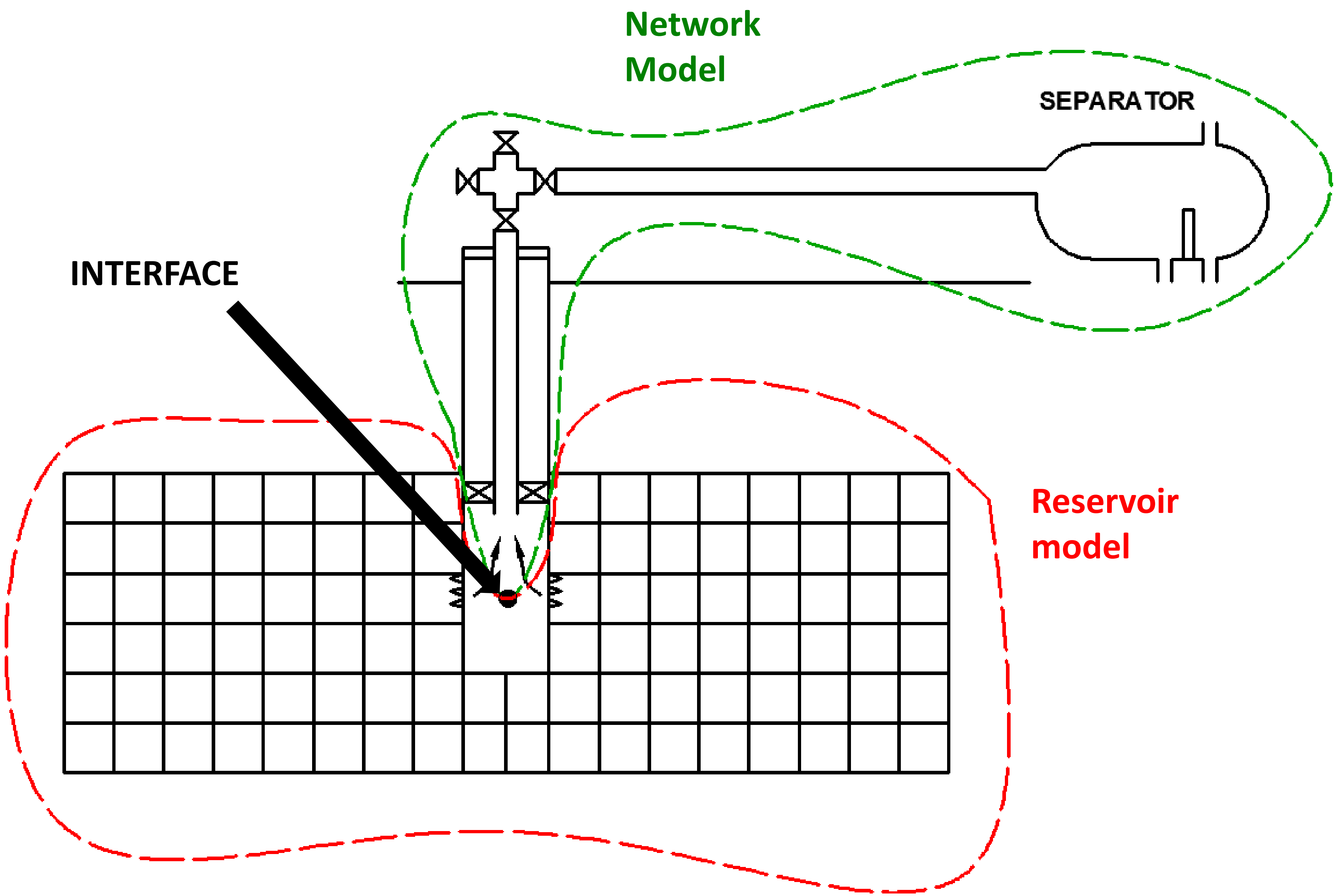
Coupling:

Connecting reservoir and network model to achieve consistency at the interface.

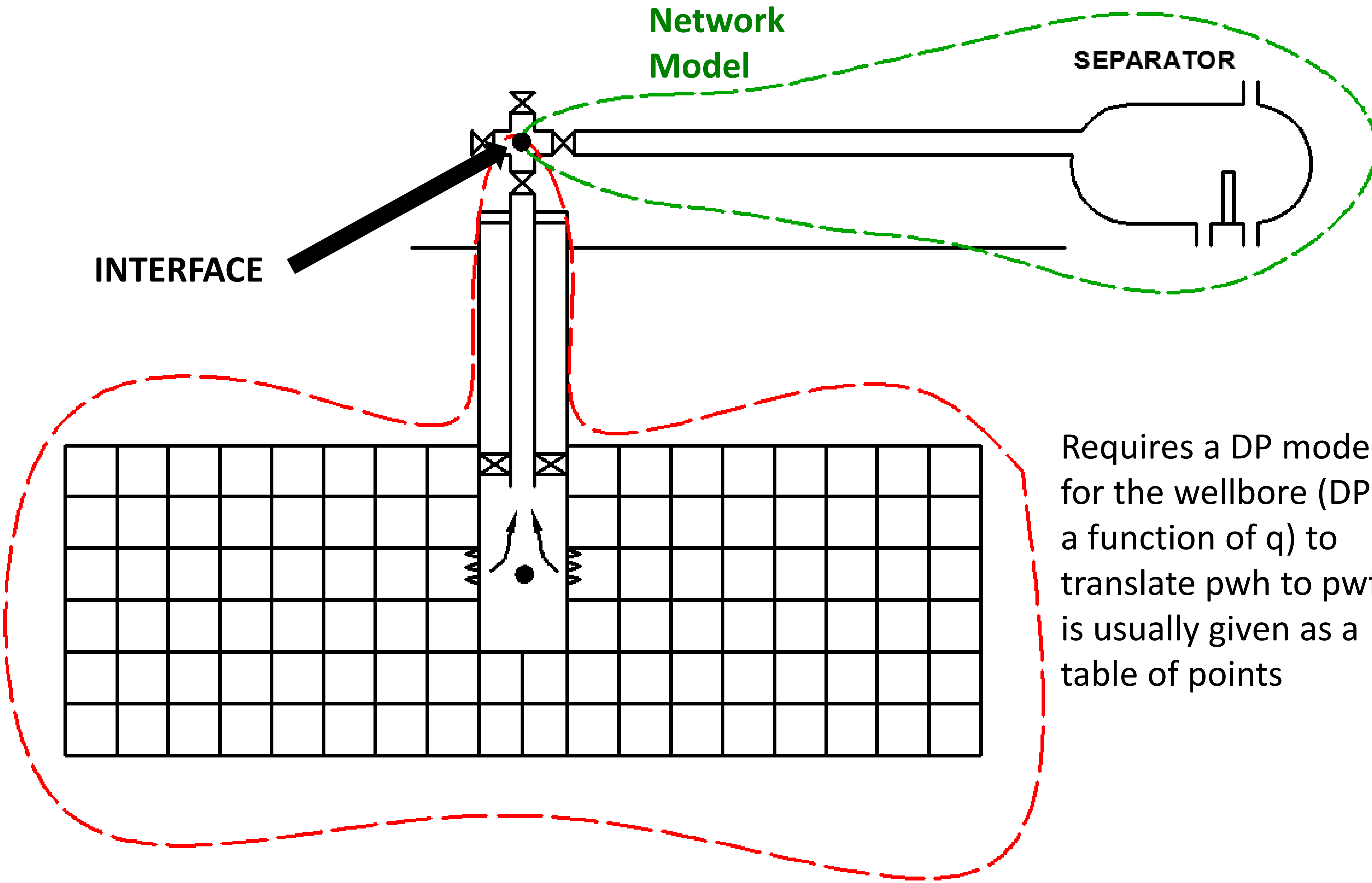
Or, equivalently:

- Will I be able to produce the reservoir rates through the well and network?
- Find realistic values for p_{wfmin}

Model's Interface: well's bottomhole



Model's Interface: wellhead



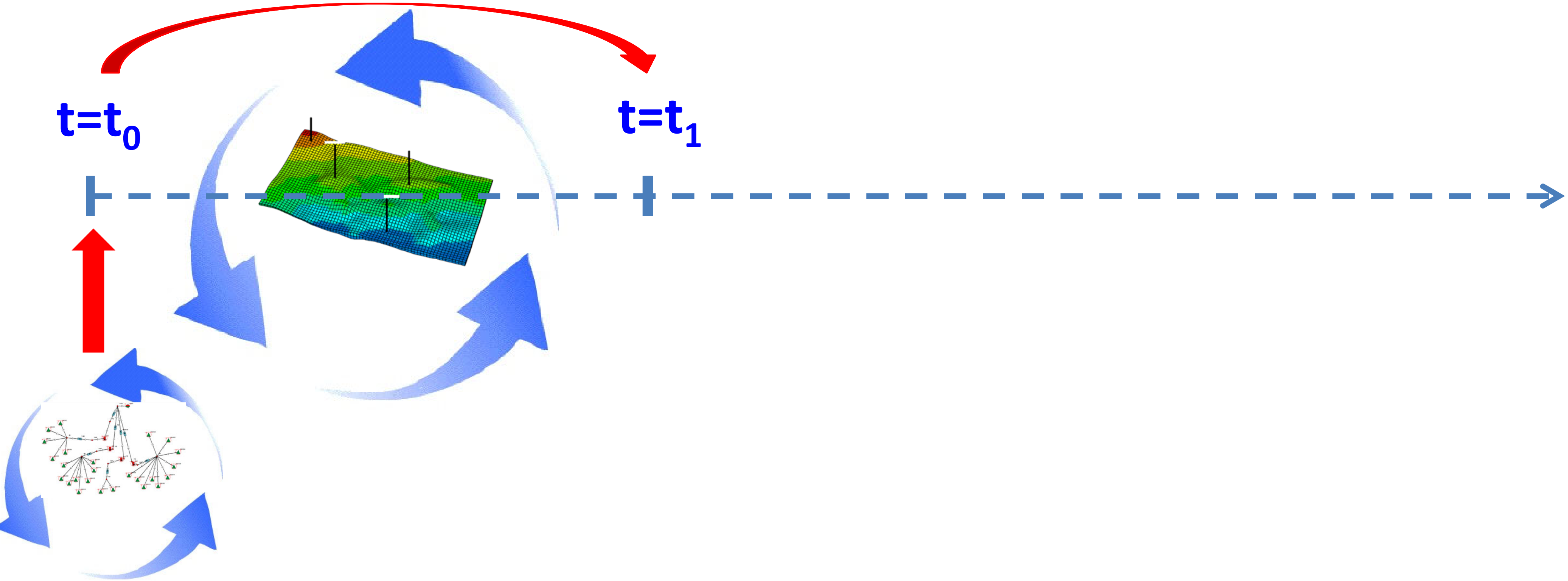
Requires a DP model for the wellbore (DP as a function of q) to translate pwh to pwf. It is usually given as a table of points

Integration strategies

- **Explicit**

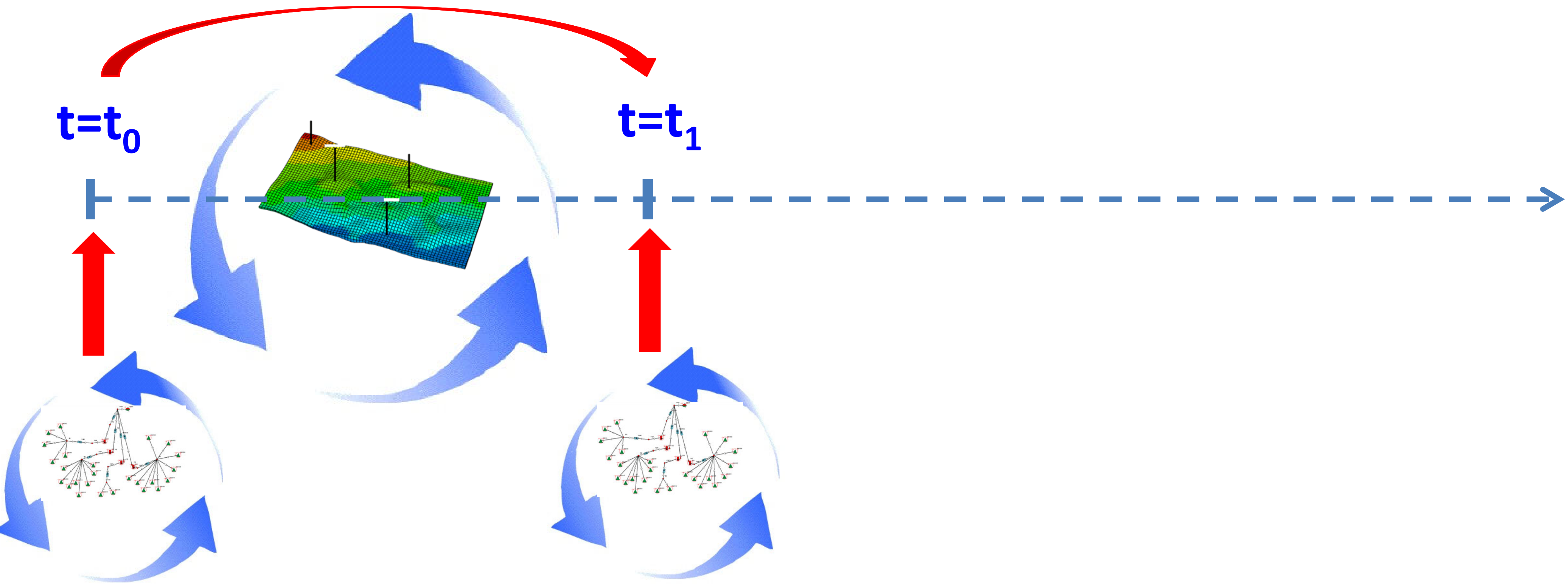
Integration strategies

- **Explicit**



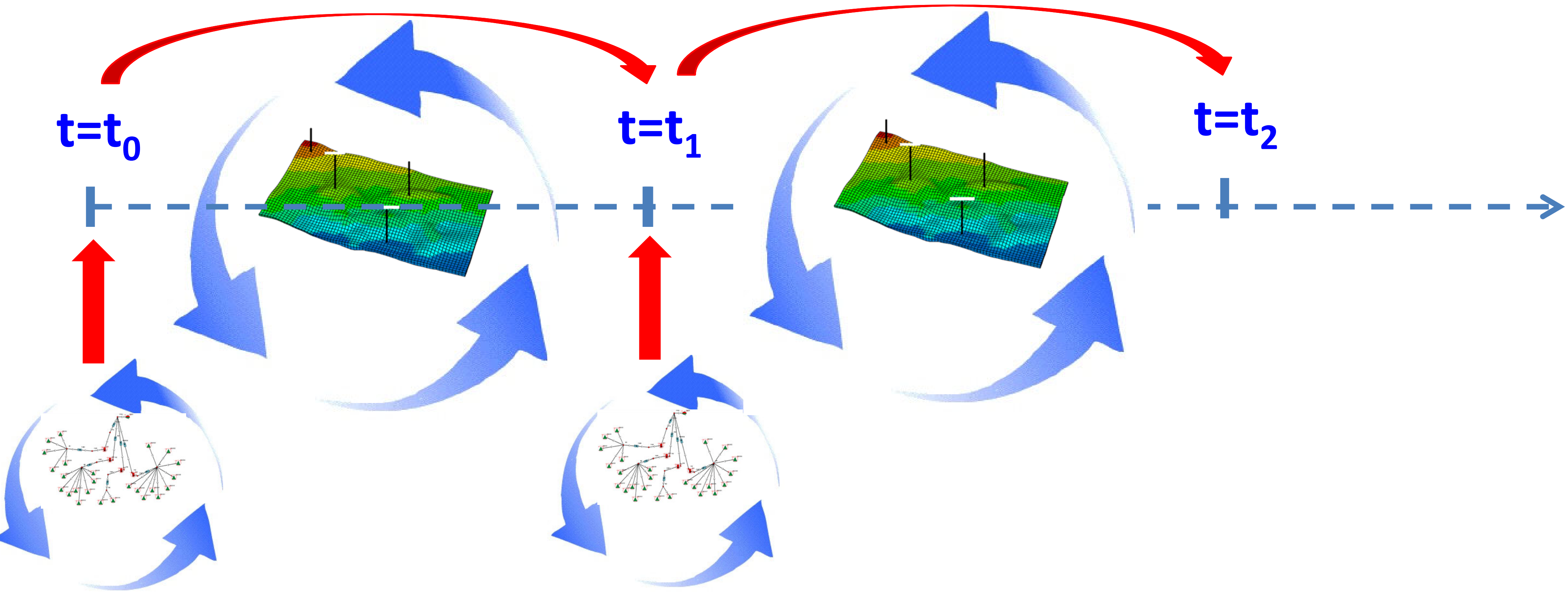
Integration strategies

- **Explicit**



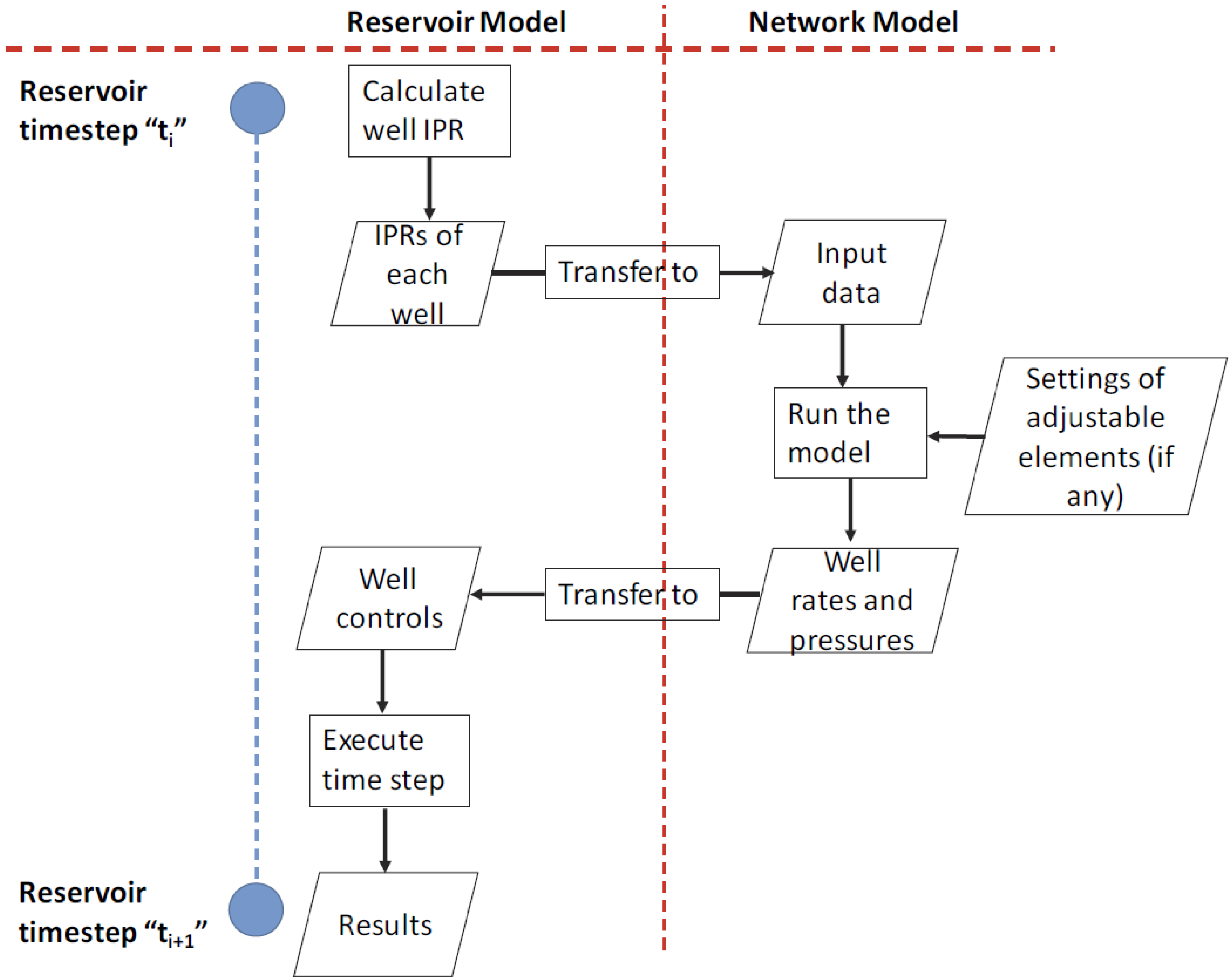
Integration strategies

- **Explicit**

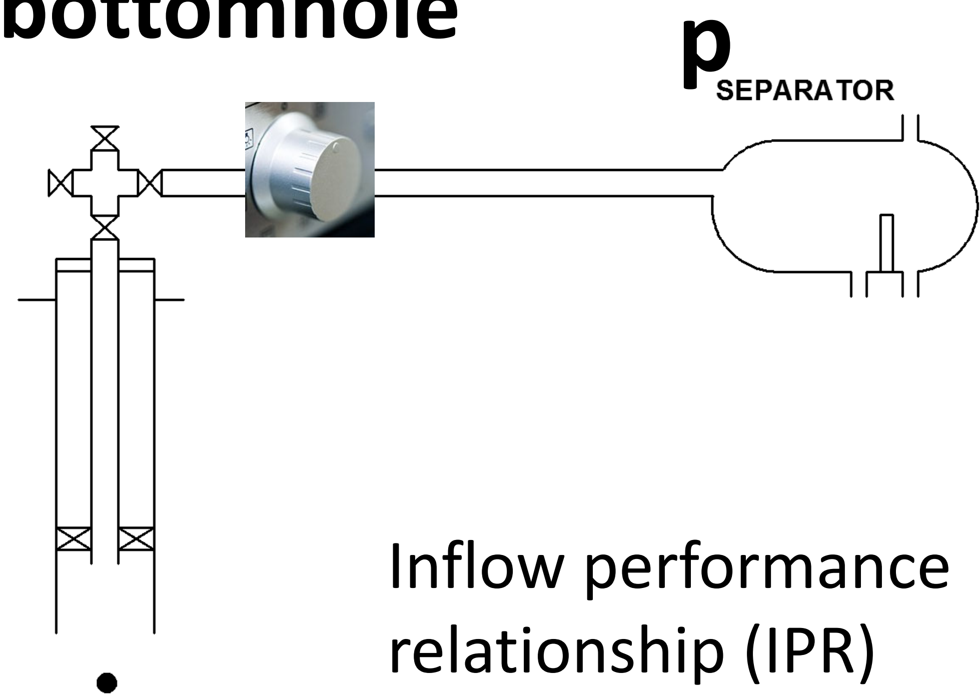


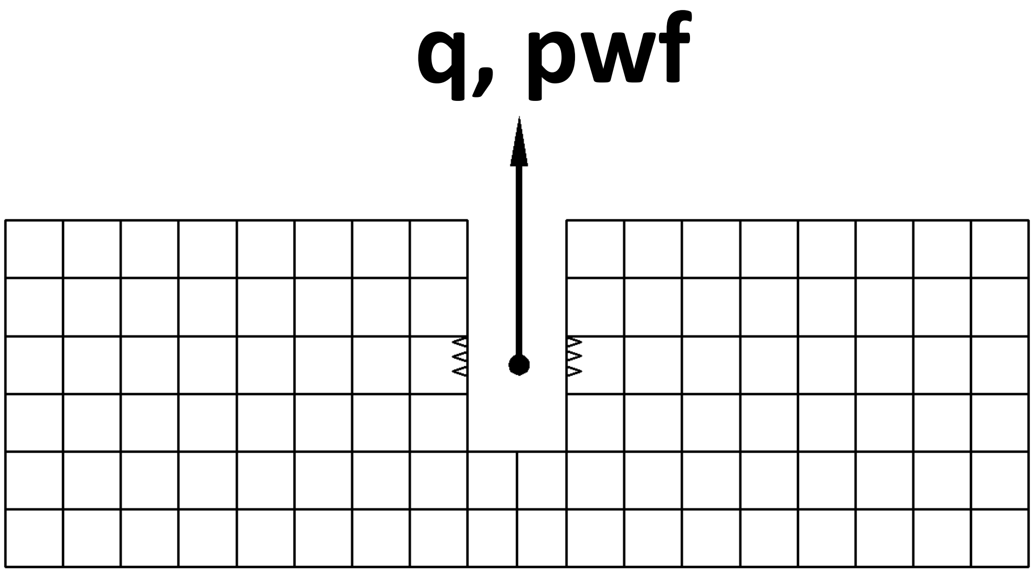
Integration strategies

- **Explicit**

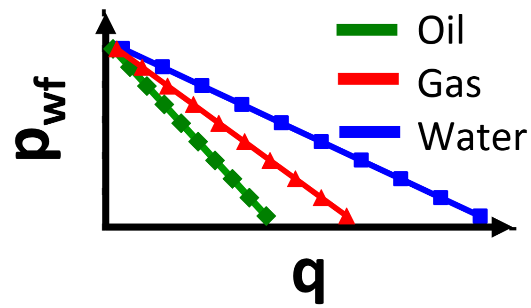


Model's Interface: well's bottomhole





Inflow performance relationship (IPR)

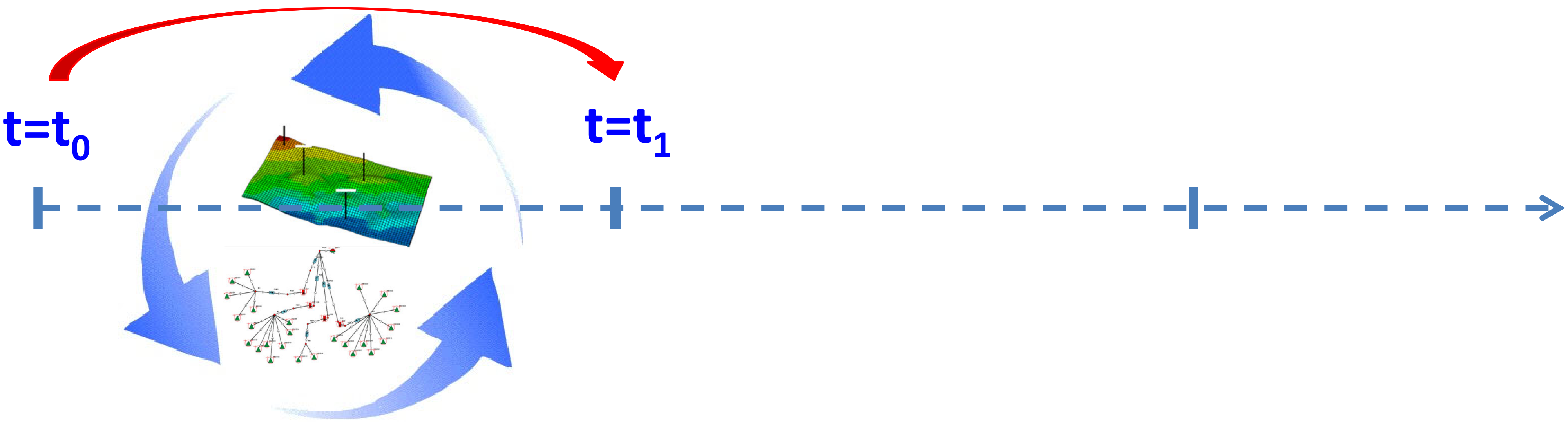


Explicit integration strategy

- Possible to integrate software from different providers
- IPR generation is required (by reservoir simulator or by the network simulator)
- Can lead to numerical instabilities. A small time-step might be required

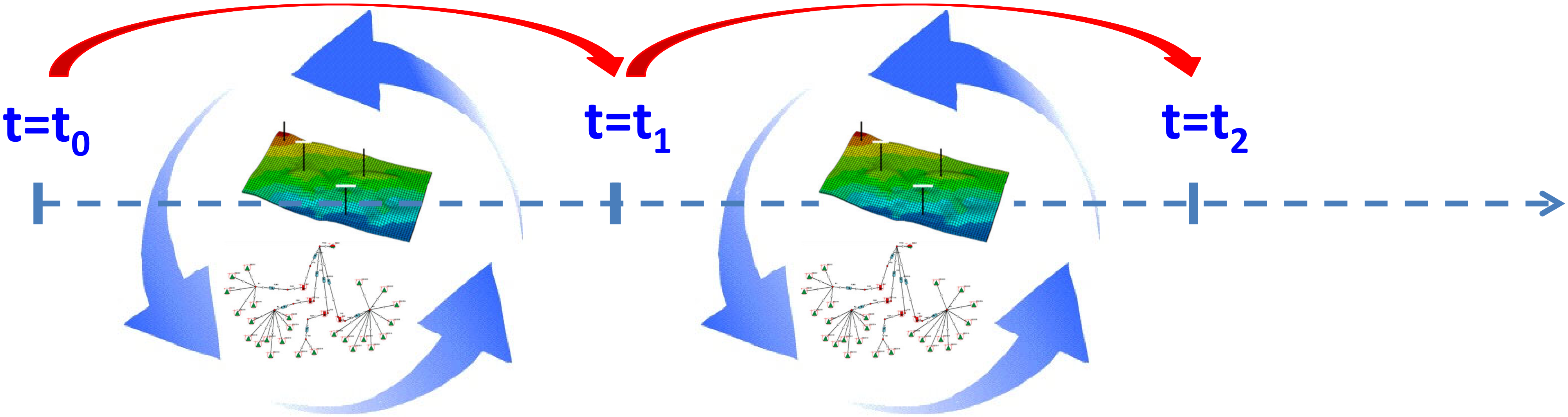
Integration strategies

- **Implicit**



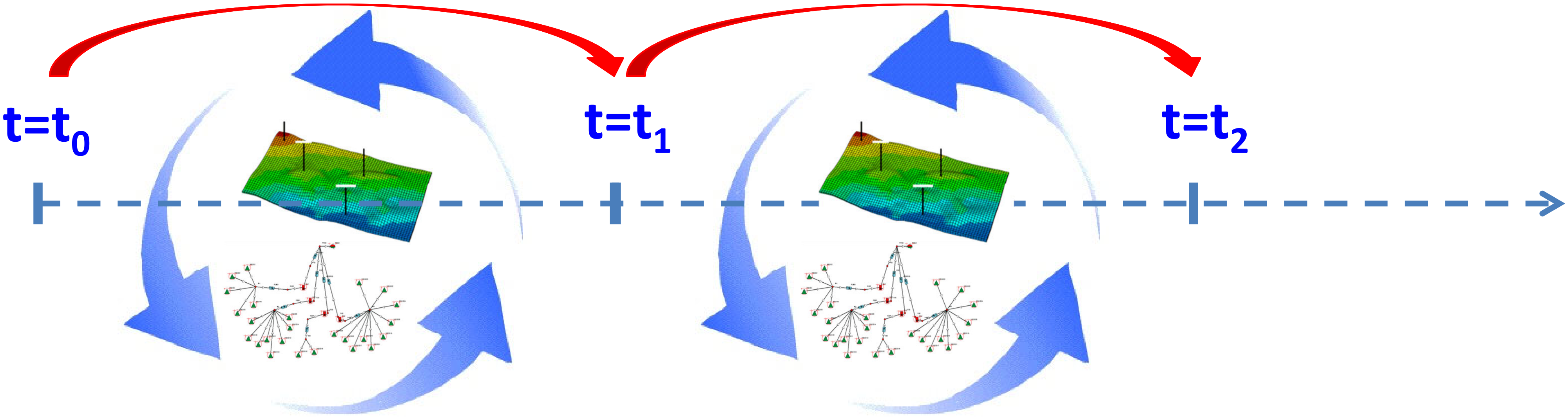
Integration strategies

- **Implicit**



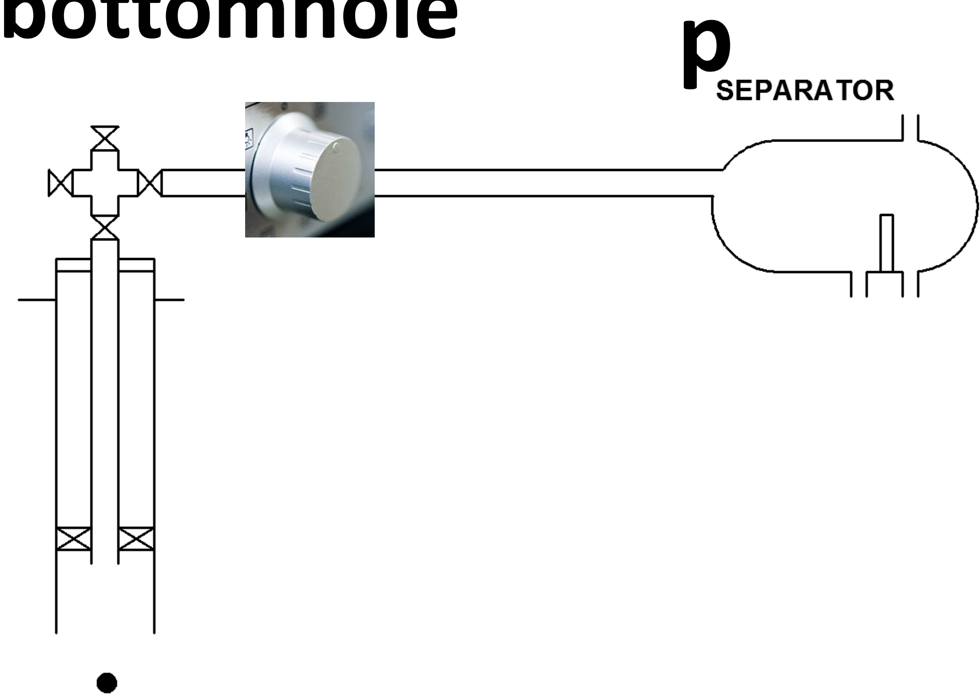
Integration strategies

- **Implicit**

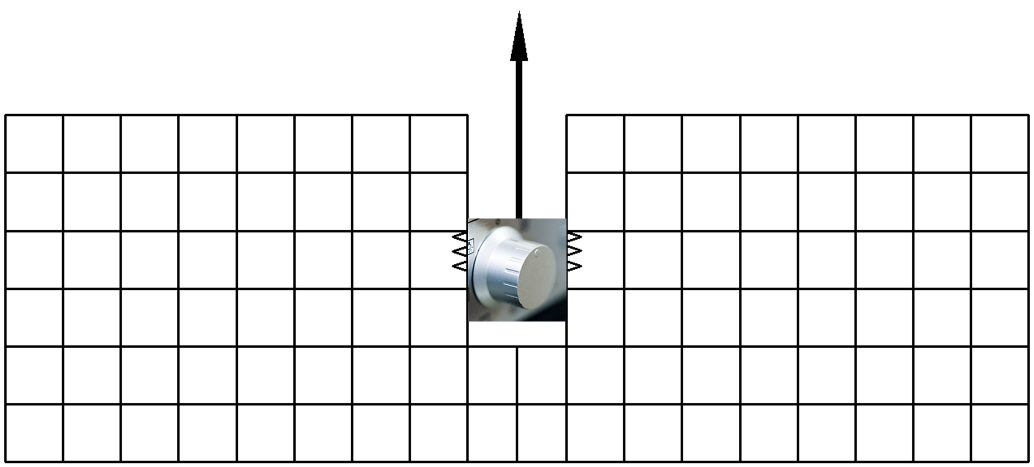


Here an IPR might not be needed

Model’s Interface: well’s bottomhole



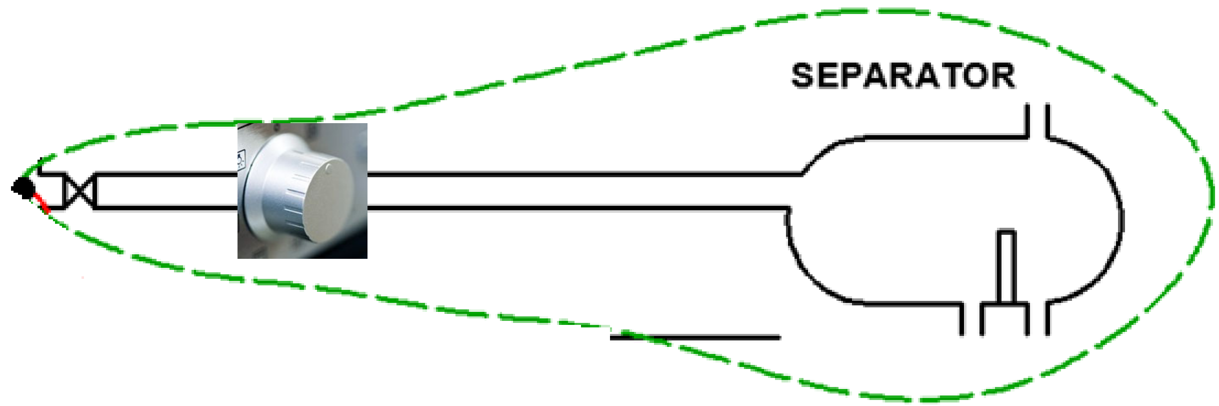
q, pwf



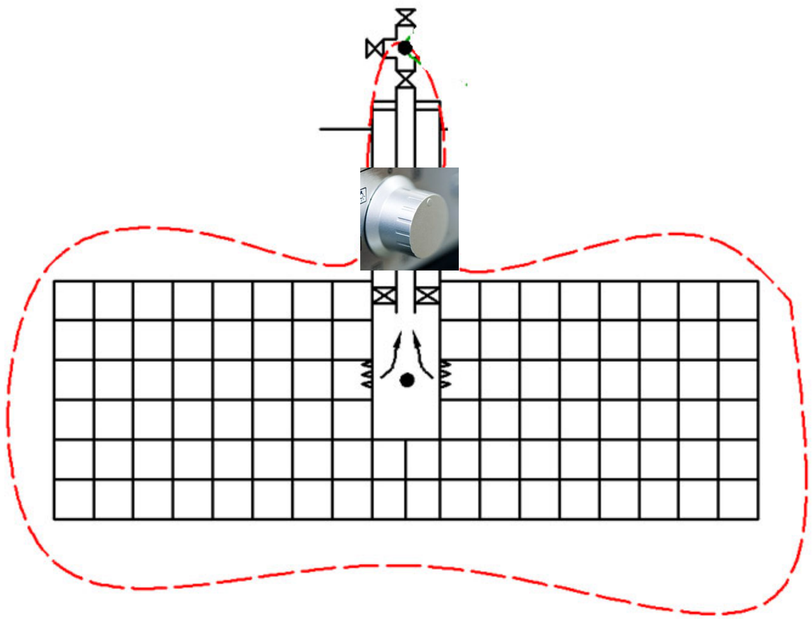
q, pwf

Model’s Interface: wellhead

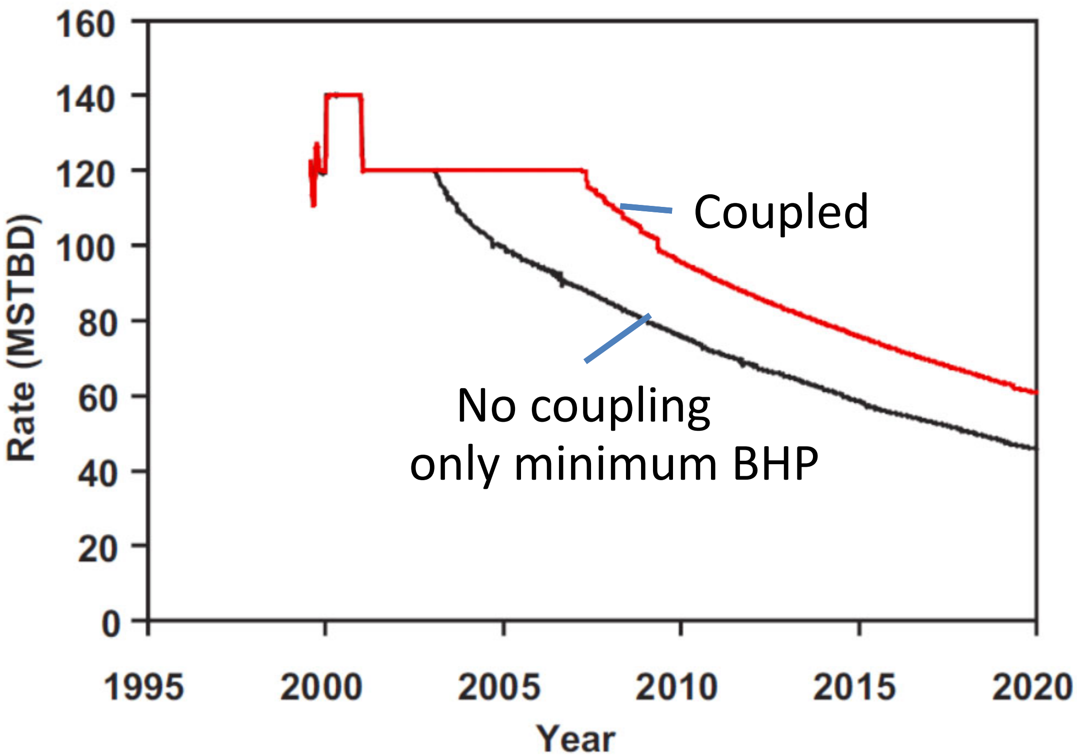
q



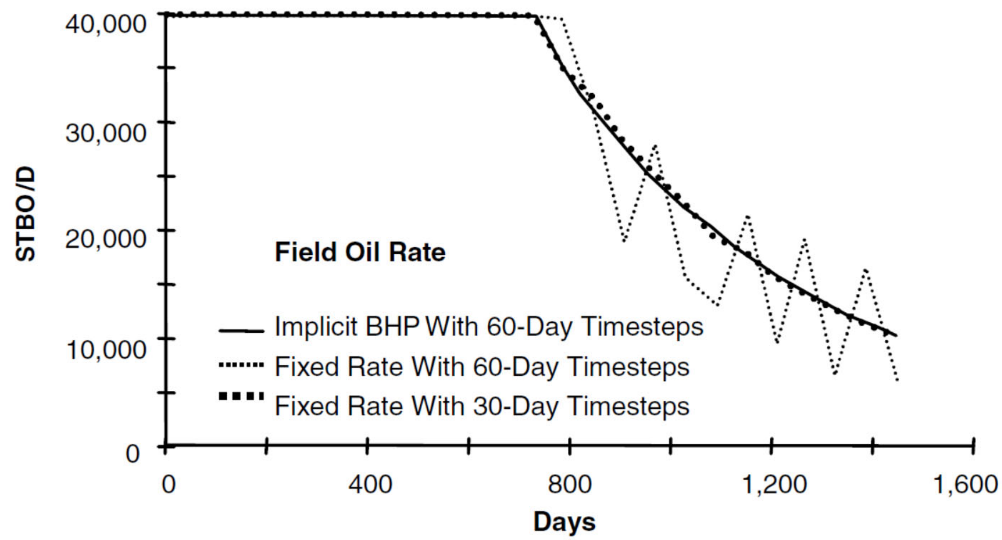
q, pwh



Examples from the literature



From Al-Shaalan, 2002

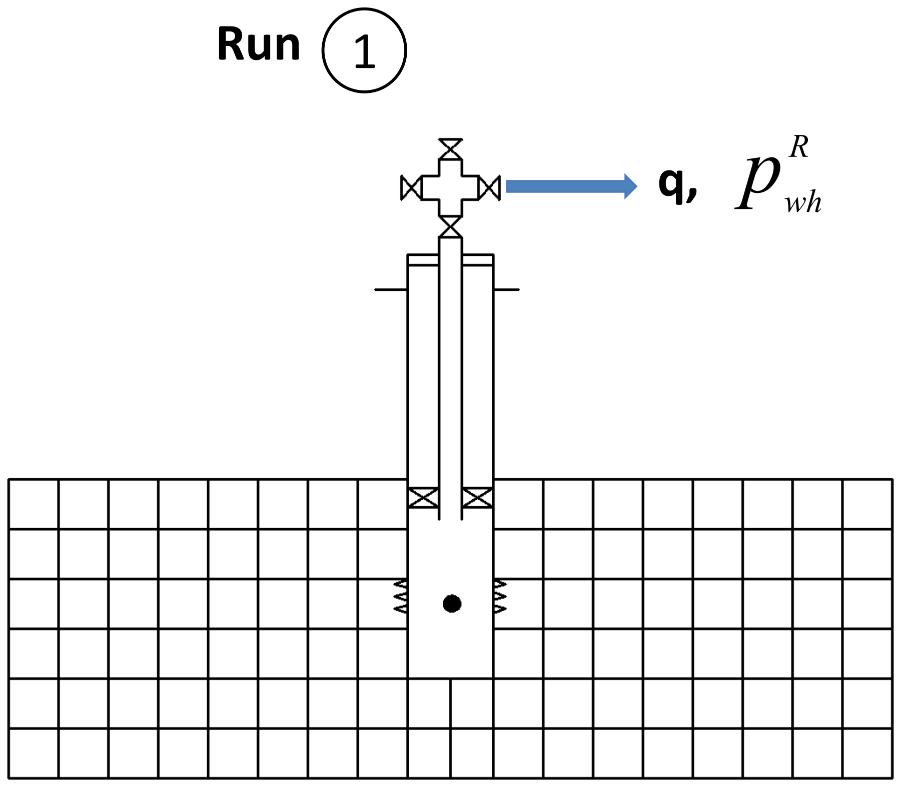


Solution instability from SPE 71120

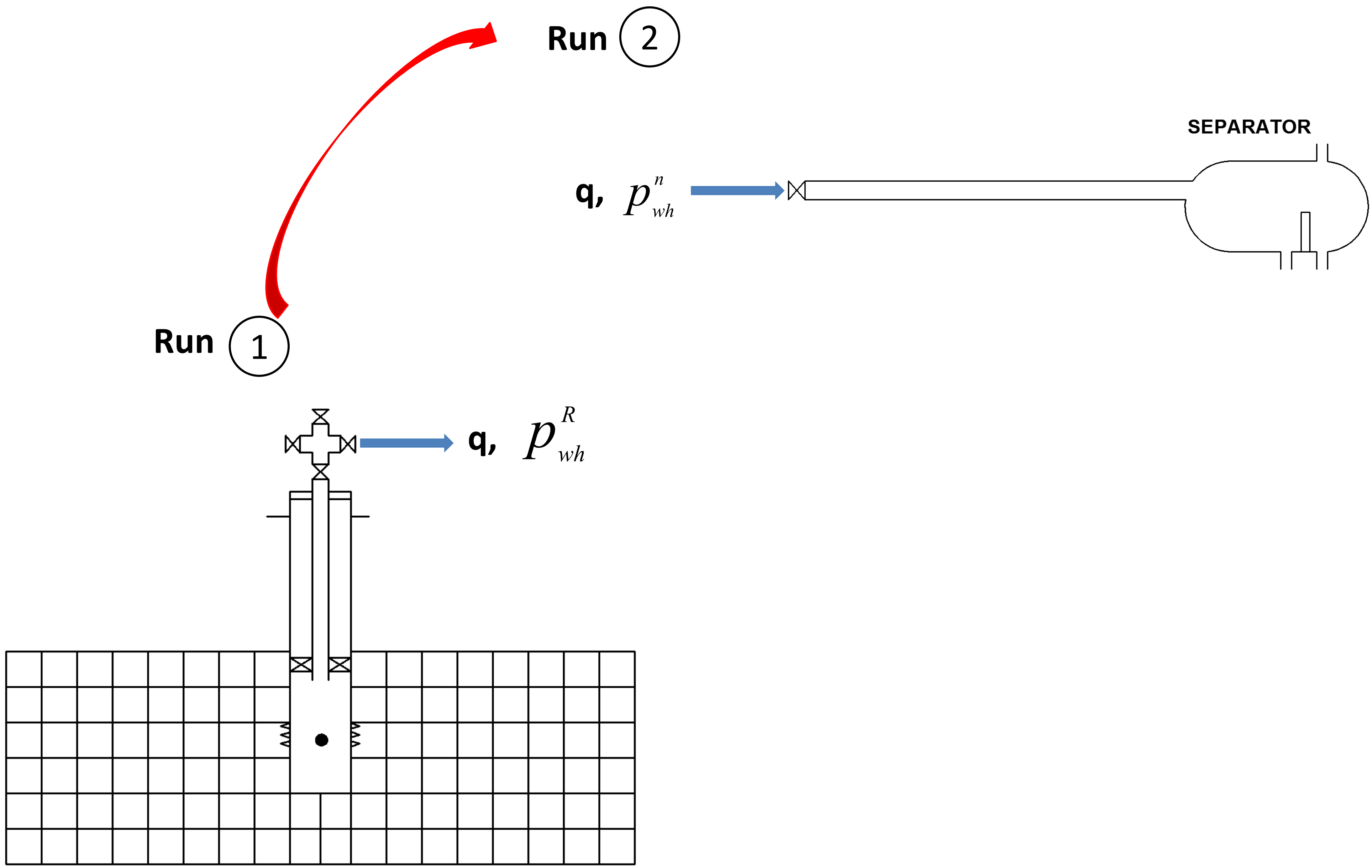
Implicit integration strategy

- Difficult to integrate software from different providers (for efficient solving, the source code should be integrated)
- IPR generation is not required
- More numerically stable, bigger time-steps can be used

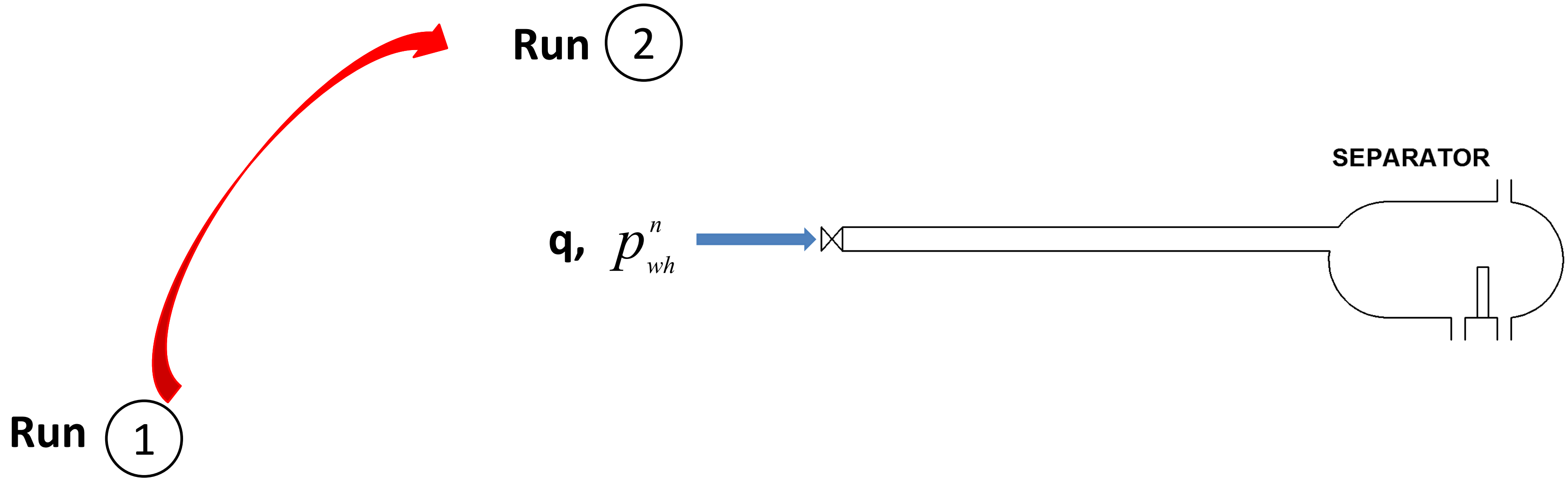
Coupling strategy for choked wells

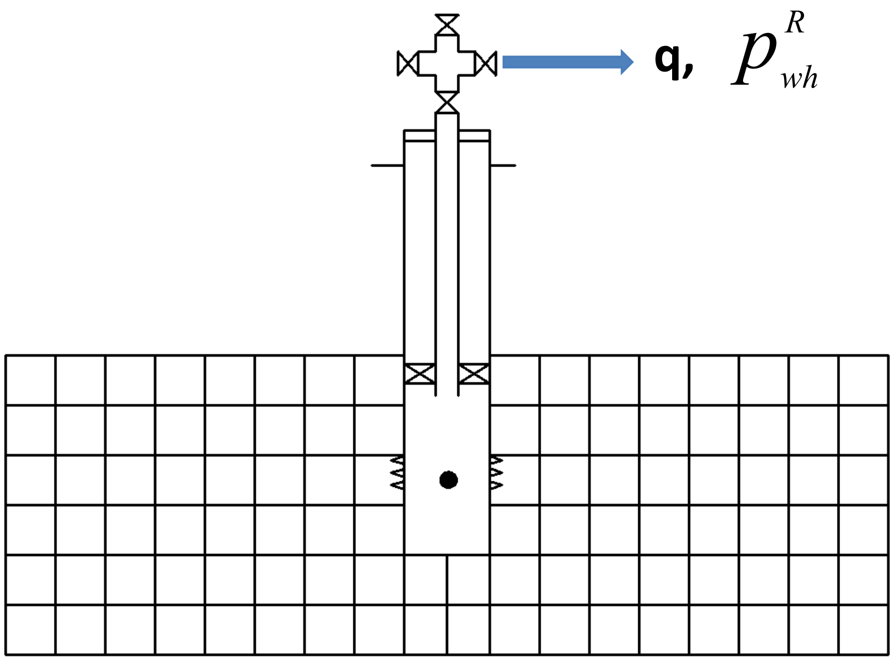


Coupling strategy for choked wells



Coupling strategy for choked wells





If $p_{wh}^{R} > p_{wh}^{n}$

- Well is choked, proceed to next reservoir time step

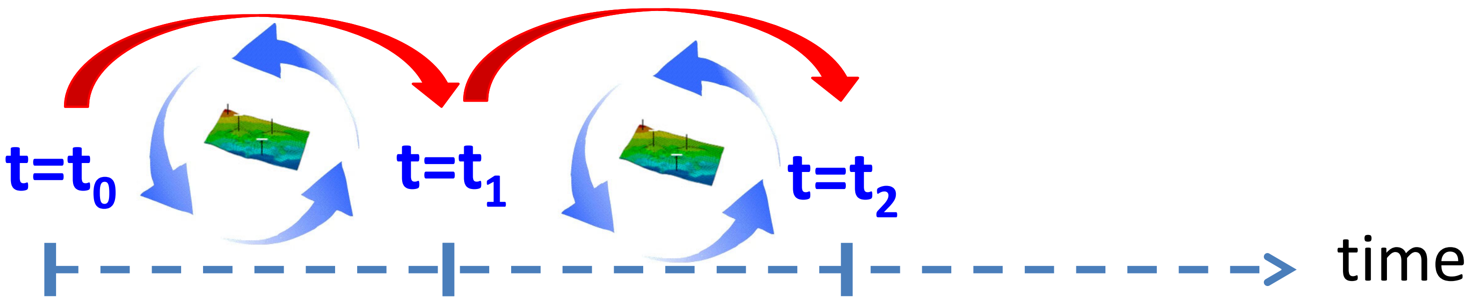
Integration strategies

- **Loose coupling with bottom-hole coupling –most typical**

Integration strategies

- **Loose coupling with bottom-hole coupling –most typical**

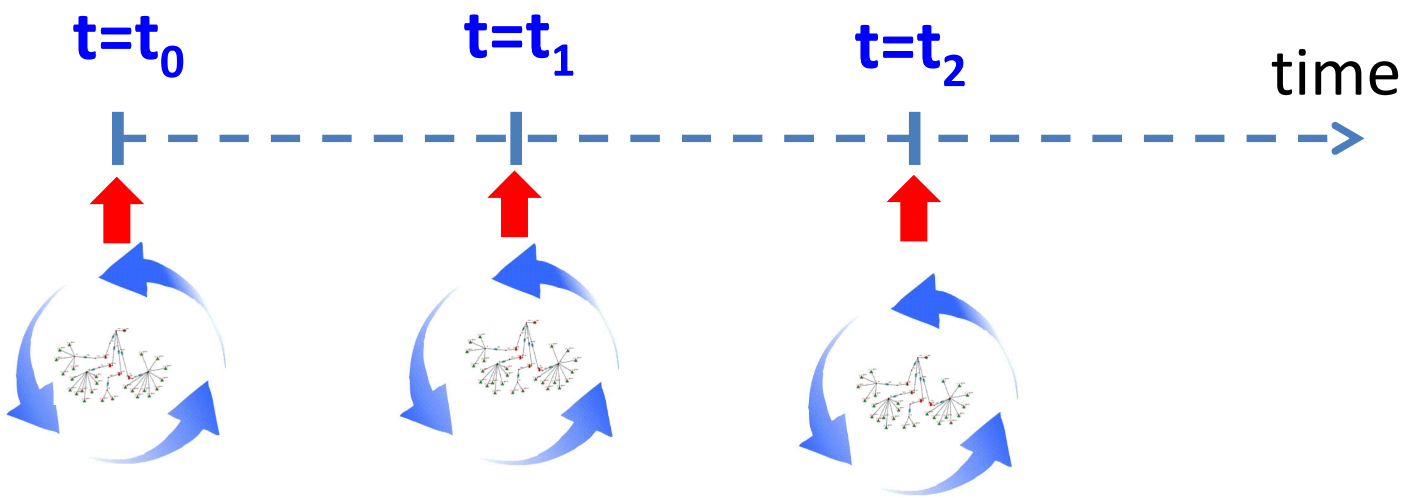
1. Assume p_{wfmin}
2. Run reservoir simulation



Obtain profiles of q(t), p_{wf} (t), IPR (t)

Loose coupling with bottom-hole coupling

3. Run network simulation with IPR(t) from step 2



4. Verify if $q_{network}(t) == q_{reservoir}(t)$. If not, provide $p_{wf}(t)$ as $p_{wfmin}(t)$ and repeat from step 1

Loose coupling integration strategy

- Easy to integrate software from different providers
- Practical for use for different engineering teams
- More time-consuming – several iterations are typically required to converge on a solution

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