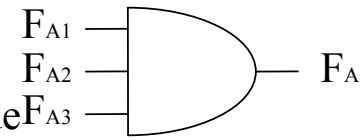
Fault Trees

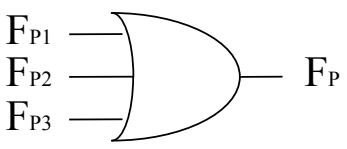
- Fault Trees
  - dual of Reliability Block Diagram
  - logic failure diagram
  - think in terms of logic where
    - » 0 = operating, 1 = failed
- AND Gate
  - all inputs must fail for the gate to fail
- OR Gate
  - any input failure causes the gate to fail
- k-of-n Gate
  - k or more input failures cause gate to fail

e.g. Triplex Bus Guardian

- Active mode
  - M_1 and M_2 and M_3 fail =>
  - AND Gate

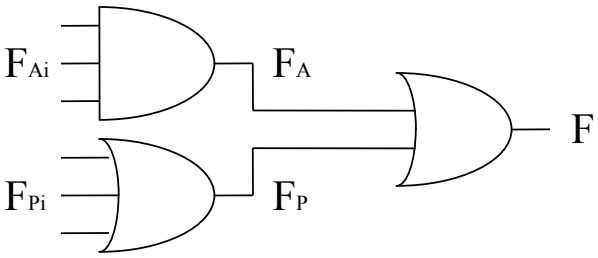


- Passive Mode
  - "cutoff" with any single unit failure =>
  - OR Gate



e.g. Triplex Bus Guardian

- Total Failure
  - caused by either active or passive mode



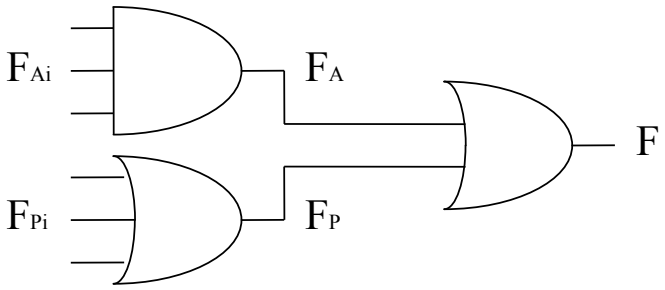
e.g. Triplex Bus Guardian

- How can one use the fault tree effectively to isolate those parts of the system that need reliability considerations?

e.g. Triplex Bus Guardian

- Combined fault model

$$Q(1000h) = 0.9851243 \cdot 10^{-6}$$



$$Q(1000h) = 0.295545 \cdot 10^{-1}$$

Examples

- Simple Passive TMR (no diagnosis)
  - RBD = (2 of 3): 2 operable => System operable
  - F-Tree = (2 of 3): 2 failed => System failed
- Simple TMR with *Benign* failures
  - RBD = (1 of 3): 1 operable => System operable
  - F-Tree = (3 of 3): 3 failed => System failed
- Summary
  - Parallel => AND
  - Series => OR
  - K-of-N => (n-k+1 of n)

SHARPE

- SYMBOLIC HIERARCHICAL AUTOMATED RELIABILITY AND PERFORMANCE EVALUATOR
- SHARPE provides a specification language and analysis algorithms for the following model types:
  - reliability block diagrams
  - fault trees
  - reliability graphs
  - series-parallel acyclic directed graphs
  - product-form queuing networks
  - Markov and semi-Markov chains
  - generalized stochastic Petri nets

  - note: we are using the latest version of SHARPE and there could be changes that are not reflected in this handout.

SHARPE

- Read the "SHARPE LANGUAGE DESCRIPTION" for details. (The material below is directly adopted from there).
- Basic language components

- **comments** '*' indicates a comment line
- **echo** *anytext* writes *anytext* to the output
- **include** *filename* takes inputs from the file indicated

  - names: command **info constants** on the current version under solaris indicates:

```
size of input line: 512
maximum number of intervals for eval: 100
number of significant characters in words: 30
maximum number of phases in a phased-mission system (pms): 100
```

SHARPE

- Basic language components
  - A *word* is a sequence of characters (no white space, commas, semicolons, ( ) \ $).
  - A *subword* is a string $*n* or $(*expression*).
    - *n* is a single letter
      - any expression can be used within the parenthesis
  - *evaluated word* provides limited means of index
    - e.g. let i =4 and j=5, then the evaluated word $(i)A-$(j-i)B-$j evaluates to the component name: 4A-1B-5
  - length of words: as before, use **info constants**

SHARPE

- Basic language components (cont.)
  - Arithmetic Expressions
    - addition +
    - subtraction -
    - negation -
    - division /
    - multiplication *
    - exponentiation ^
    - "power of e" ^

SHARPE

- Basic language components (cont.)
  - Arithmetic Expressions
    - » evaluated from left to right
    - » examples:

```
360 / (360 + (k-1) * x)
k * x * (1 - c(x, k))
3 * lambda * prob (second-fault, recovered; 2*lambda)
^(-(k-1) * x * tau)
delta / ((k-1) * x) * (1 - ^(-(k-1) * x / delta))
sum (i,1,n,sum(j,1,i,j))
sum (i,1,n,prob(m,\$(i)-\$(j)))
```


SHARPE

- Basic language components (cont.)
  - simple variables (*simple_var*), a *name* that must be bound to a value

bind *simple_var expression*

bind
<simple_var expression>
end

  - function

func *function_name (param_list) expression*

  - defined variable (is the same as a function without arguments)

var *defined_var expression*

SHARPE

- Basic language components (cont.)
  - Scope of names and words
    - » simple/defined variables, function names, model names, exp. polynomial names are global
    - » component names are local to the model in which they appear
    - » parameter names are local to their system, function etc.
    - » index of a loop is local to the loop
    - » index of a sum function is local to the function

  - parameter list *(param_list)*

  name, name, … , name

  - argument list *(arg_list)*

  expression, expression, … , expression

cdf F(t)

- *F(t)*, is the cumulative distribution function for the failure probability of the component.
- *F(t)* is the probability that component *i* has failed by time *t*. SHARPE can compute the system failure distribution function and the mean and variance of the function. It can be asked to evaluate the function at particular values of *t*.

$$F(t) = \sum_{j=1}^{k} a_j t^{k_j} e^{b_j t}$$

real or complex | non negative integer | real or complex

SHARPE Command Language

- Model Definition
- Binding Values to Variables
- Calling Functions
- Printing (with built-in functions)

- silly details
  - * comment
  - \ line continuation
  - names are truncated to 14 characters

Reliability Block Diagram (RBD)

- block
- comp
- parallel
- series
- kofn

SHARPE manual page 22

Fault Trees

- ftree
- basic
- repeat
- transfer
- and
- or
- kofn

SHAPRE manual page 23

Calling Functions + Printing

- See Section B.5 of the SHARPE manual for details

- **cdf** (*system_name* {,*state_eword*} {;*arg_list*}
  - all models except irreducible chain or gspn.
- *state_eword* used only in markov chains
- *arg_list* matches # of parameters in system definition
  - prints cdf, mean, variance
- **expr** *expression* {,*expression*...}
  - sharpe prints the value of the *expressions*
  - e.g.
    - expr(lambda)
    - expr(lam_a + lam_b)

Calling Functions + Printing

- **eval**(*system_name* {;*state_eword*}{;*arg_list*} *lhi* {*function*}
  - same as for cdf
- *lhi* = low, high, increment are all expressions
- *function* is cdf (default) or any other function
  - e.g. generate F(t) for t specified and print result
  - for Markov chain
    - argument {;state} allows to evaluate the probability of being in the state specified.
- *lhi* low, high, increment e.g.
    - 100 200 25
    - evaluate F(t) at t = 100, 125, 150, 175 and 200 hours

Calling Functions + Printing

- * comment
- **echo** *string*
  - echoes *string* to the output
  - e.g. echo this is just a test
- **var** *var_name expression*
  - defines variable *var_name*
  - assigns the value in *expression*
  - does not print

Calling Functions + Printing

- **value**(*t* ;*system_name* {,*state_eword*} {;*arg_list*}
  - calculates value of cdf at time *t*
  - does not print
  - use on right hand side of **var**
  - e.g.
    - var Fat1000 value(1000;bus_gd_pass)
    - expr Fat1000
- **format** *constant*
  - number of digits after decimal point to be printed

Calling Functions + Printing

- Values of "epsilon"
  - user-controlled epsilon: small values that determine when algorithms have converged or two floating point numbers are equal

    epsilon *epsilon_id expression*

  - **basic** determines when two floats are even
  - **result** determines when a printed result is considered to be zero

  - e.g.
    - epsilon basic 1.0*10^-11
    - epsilon results 1.0*10^-10

Bus Guardian (Passive)

```
* SYSTEM: TRIPLEX BUS GUARDIAN -- PASSIVE FAILURE MODE
* MODEL: RELIABILITY BLOCK DIAGRAM
* -- Model Definition: block name, components, connectivity --
*
block bus_gd_pas
comp z exp(lampas)
series z3 z z z
end

* -- Bind Values to Variable Names --
*
bind
lampas 1.0*10^-5
end
```

```
* -- Calculate CDF for System Failure --
*
cdf(bus_gd_pas)

* -- Evaluate CDF at Specified Points --
eval(bus_gd_pas) 9 11 1
eval(bus_gd_pas) 90 110 10
eval(bus_gd_pas) 900 1100 100
*
var   Qat1000 value(1000; bus_gd_pas)
expr  Qat1000

end
```


Bus Guardian (Passive)

```
CDF for system bus_gd_pas:

   1.0000e+00 t(  0) exp( 0.0000e+00 t)
 + -1.0000e+00 t(  0) exp(-3.0000e-05 t)

mean: 3.3333e+04
variance: 1.1111e+09

----------------------------------------

    system bus_gd_pas
    t              F(t)
 9.0000 e+00  2.6996 e-04
 1.0000 e+01  2.9996 e-04
 1.1000 e+01  3.2995 e-04
```

```
  system bus_gd_pas
    t              F(t)
 9.0000 e+01  2.6964 e-03
 1.0000 e+02  2.9955 e-03
 1.1000 e+02  3.2946 e-03

----------------------------------------
    system bus_gd_pas
    t              F(t)
 9.0000 e+02  2.6639 e-02
 1.0000 e+03  2.9554 e-02
 1.1000 e+03  3.2461 e-02

 Qat1000:   2.9554e-02
```

Bus Guardian (Active)

```
* SYSTEM: TRIPLEX BUS GUARDIAN -- ACTIVE FAILURE MODE
* MODEL: RELIABILITY BLOCK DIAGRAM
* -- Model Definition: block name, components, connectivity --
*
block bus_gd_act
comp z exp(lamact)
parallel z3 z z z
end

* Bind Values to Variable Names
*
bind
lamact 1.0*10^-5
end
```

```
* -- Calculate CDF for System Failure
*
cdf(bus_gd_act)

* -- Evaluate CDF at Specified Points
eval  (bus_gd_act)  9  11  1
eval  (bus_gd_act)  90  110  10
eval  (bus_gd_act)  900  1100  100
*
var   Qat1000 value(1000; bus_gd_act)
expr  Qat1000
end
```


Bus Guardian (Active)

```
CDF for system bus_gd_act:

   1.0000e+00 t(  0) exp( 0.0000e+00 t)
 + -3.0000e+00 t(  0) exp(-1.0000e-05 t)
 +  3.0000e+00 t(  0) exp(-2.0000e-05 t)
 + -1.0000e+00 t(  0) exp(-3.0000e-05 t)

mean: 1.8333e+05
variance: 1.3611e+10
----------------------------------------
     system bus_gd_act
     t        F(t)

 9.0000 e+00  0.0000 e+00
 1.0000 e+01  0.0000 e+00
 1.1000 e+01  0.0000 e+00
```

```
     system bus_gd_act
     t        F(t)

 9.0000 e+01  0.0000 e+00
 1.0000 e+02  0.0000 e+00
 1.1000 e+02  1.3288 e-09

----------------------------------------
     system bus_gd_act
     t        F(t)

 9.0000 e+02  7.1923 e-07
 1.0000 e+03  9.8512 e-07
 1.1000 e+03  1.3092 e-06

 Qat1000:   9.8512e-07
```