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INCREASED SAFETY BY FAULT TOLERANT SOFTWARE - JUST ANOTHER WAY TO WASTE MONEY?

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HIGHLY COMPETITIVE COMPETITION

- my new car !

MSR
ASR
ABS EBV
ESP USC

- my new software toolkit ?

BOOP ASPECT
CORE TL ADT OOP VDM++
SADT HOL JSD LOTOS
RBD MASCOT VDM
DFD CCS CSP
FTA OBJ Z
SA
NVP CTL/LTL RBS
MTBF MTTF MTTR

INTERNATIONAL STANDARD

- IEC 61508
  Functional safety of
  electrical/electronic/programmable electronic safety-related systems

- part 7
  Overview of techniques and measures,
  first edition August 2002

- Annex C
  Overview of techniques and measures for achieving software safety integrity

- C.2 Requirements and detailed design
  - *-> C.2.5 Defensive programming*

- C.3 Architecture design
  - *-> C.3.1 Fault detection and diagnosis*
  - *-> C.3.2 Error detecting and correcting codes*
  - *-> C.3.3 Failure assertion programming*
  - *-> C.3.4 Safety bag*
  - *-> C.3.5 Software diversity*
  - *-> C.3.6 Recovery block*
  - *-> C.3.7 Backward recovery*
  - *-> C.3.8 Forward recovery*
  - *-> C.3.9 Re-try fault recovery mechanisms*
  - *-> C.3.10 Memorising executed cases*
  - *-> C.3.11 Graceful degradation*
  - *-> C.3.12 Artificial intelligence fault correction*
  - *-> C.3.13 Dynamic reconfiguration*

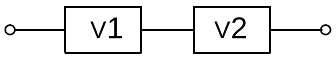
METHODS TAXONOMY

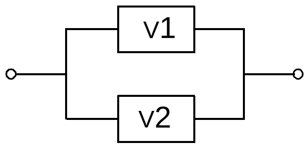
SOFTWARE DEPENDABILITY

- FAULT AVOIDANCE --> *development phase*
  - FAULT PREVENTION
  - FAULT REMOVAL
    - MANUAL
    - COMPUTER-AIDED
      - animation / simulation / testing
      - context checking (static analysis)
      - consistency checking (verification)
- FAULT TOLERANCE --> *operation phase*
  - FAULT MASKING
    - DEFENSIVE
    - DIVERSITY
  - FAULT RECOVERY

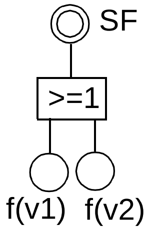
SYSTEM FAILURE / RELIABILITY - BASICS

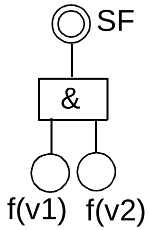
RELIABILITY BLOCK DIAGRAM





FAULT TREE





LOGICAL FUNCTION

SF = f(v1) <u>or</u> f(v2) SF = f(v1) <u>and</u> f(v2)

PROBABILITY FUNCTION

p(SF) = 1-[(1-p(v1)) * (1-p(v2))]

p(SF) = p(v1) * p(v2)

e.g. p(v1) = p(v2) = 0.1

p(SF) = 0.19 p(SF) = 0.01

CAUTION: vi must be statistically independent

DEFENSIVE PROGRAMMING

- **ERROR DETECTING/CORRECTING CODES**

  -> sensitive information

  parity bits, Hamming codes, . . .

- **TRISTATE BRANCHING**

  -> integrity check on (finite discrete) data types

```
if b
   then thenAction
   else elseAction
endif
```

```
if b = true
   then thenAction
   else if b = false
   then elseAction
endif
```

- **SIGNATURES**

  -> sequence errors in data/instruction streams

  -> compile time:
  compute signature Sc for each instruction block,
  insert signature Sc at reference point

  -> run time:
  re-compute signature Sr,
  at each reference point: Sc = Sr ?

- **TIMING CHECKS**

  -> time outs, watchdog timers

Failure Assertion Programming

- ❑ plausibility checks on (input/internal/output) variables

  -> robust programming

```
if x >= 0
   then y := my_sqrt(x)
   else exceptionHandling
endif
```

```
assert x >= 0;
y := my_sqrt(x);
   .
   .
   .
   .
exception
   when assertFail => exceptionHandling
end exception
```

- ❑ logical checks on system states

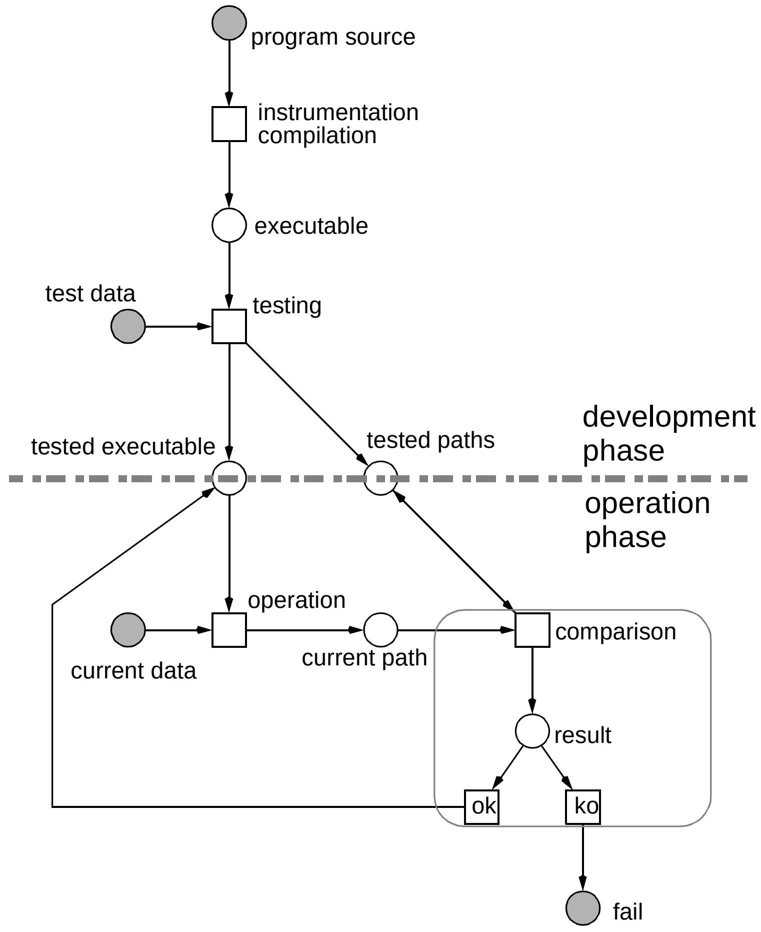
  -> detection of design faults

```
. . .
assert x > 0;        // pre-condition
   y := my_sqrt(x);
assert y*y = x;      // post-condition
. . .
```

-> run-time evaluation of assertions
from thorough program verification approaches

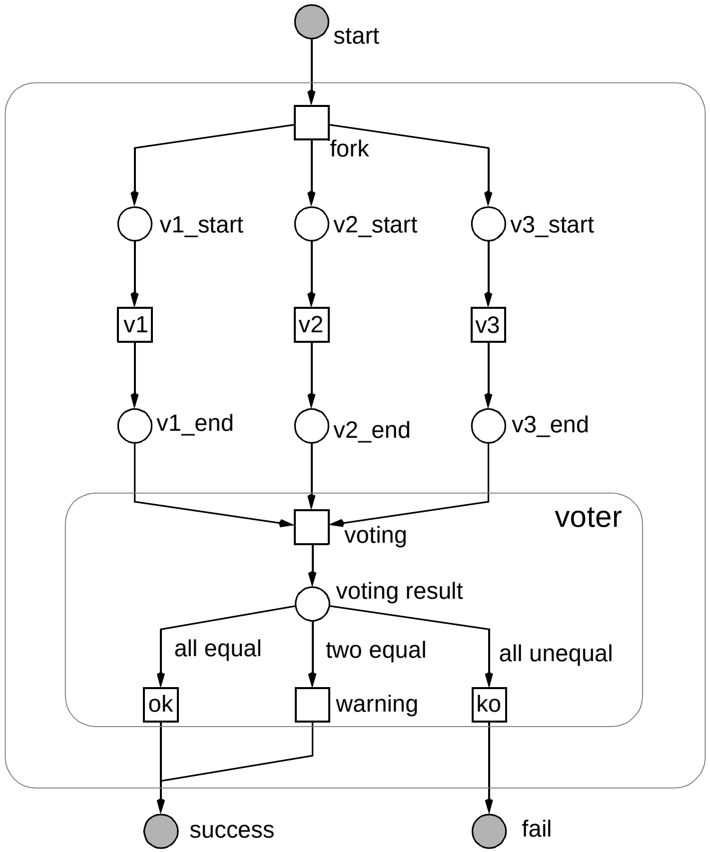
Memorising Executed Cases

-> to prevent the execution of un-known paths



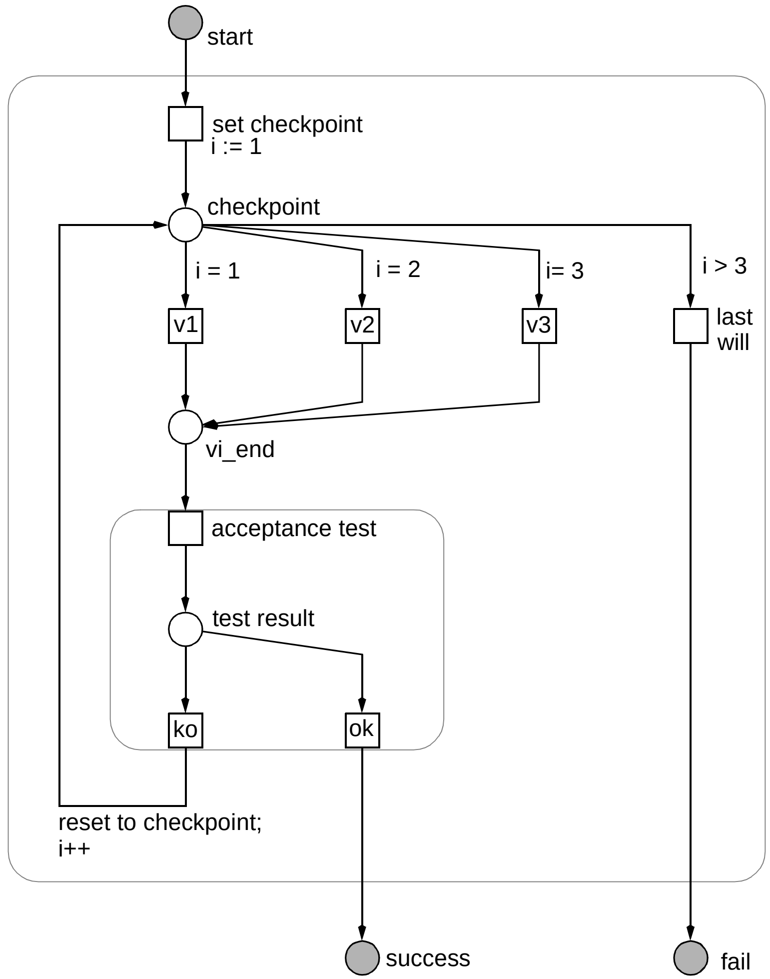
N VERSION PROGRAMMING

-> parallel execution of n program versions, followed by majority test



RECOVERY BLOCK SCHEME

-> alternative execution of n program versions, each followed by acceptance test



SUMMARY SOFTWARE DIVERSITY

- comparison

n version programs	recovery block scheme
parallel versions	alternative versions
equal functionality necessary	gracefully degraded functionality possible
relative result test (voter)	absolute result test (acceptance test)
hardware cheaper than run time	run time cheaper than hardware
hot redundancy	cold redundancy

- versions are embedded in program frame
  -> flow control between versions and tester
  -> reliability bottle-neck

- key assumptions
  -> error-free program frame
  -> comparable results by identical interpretation of (semi-formal) requirement specification
  -> independent faults in all versions / testers

DIVERSITY ASPECTS

- versions are developed by different persons/teams of
  -> different education / universities
  -> different professional background
  -> different cultural circles

- versions are developed using
  -> different software process models
  -> different designs
  -> different specification/programming languages
  -> different programming styles
  -> different tools (compiler, translator, debugger, ...)

- *versions are produced for different environments*
  -> different hardware
  -> different operating systems
  -> different libraries

- *versions are based on*
  -> different algorithms
  -> different data structures
  -> different (graceful degraded) functionality

FAULT RECOVERY

- **BACKWARD RECOVERY**

  reset to an earlier consistent internal state

  -> regular checkpointing necessary

  -> danger: domino effect !

- **FORWARD RECOVERY**

  obtain a state, which will be consistent some time later

  -> real-time systems
  with fast rate of internal state changes

- **RE-TRY FAULT RECOVERY MECHANISMS**

  re-executing the same code
  (re-boot the whole system ... re-start a procedure)

  -> exploiting non-reproducability

- **GRACEFUL DEGRADATION**

  maintaining the more critical system functions
  by dropping the less critical functions

- **DYNAMIC CONFIGURATION**

  remapping the logical architecture
  onto the currently available (restricted) resources

SUMMARY

- fault tolerance allows ***basically***
  higher system reliability than components' reliability

- software fault tolerance = redundancy + DIVERSITY

- (diverse) fault tolerance is extremely expensive

  -> *development & operation phase*

  -> *time & human/hardware resources*

  -> *what is more expensive:*
  thorough validation or fault tolerance ?

- fault tolerance involves increased complexity

  -> *complexity <-> fault avoidance*

  -> *fault tolerance <-> reuse of trustworthy components*

  -> *advanced software engineering skills*

- fault tolerance is no substitute for fault avoidance

- tailored amount of fault tolerance requires
  sound software reliability measures

fault tolerance is no substitute for thinking

-> THINK TWICE BEFORE USING FAULT TOLERANCE !

LOOK TWICE FOR SUITABLE MODULE SIZES !

DISCLAIMER'S

- "The references should be considered as basic references to methods and tools or as examples, and may not represent the state of the art." p. 23
- "The overview of techniques contained in this annex [C] should not be regarded as either complete or exhaustive." p. 115
- "Currently, at the time of developing this standard, it is not clear whether object-oriented languages are to be preferred to other conventional ones." p. 169
- "If a specific language is not listed in the table, it must not be assumed that it is excluded." p. 173

FURTHER READING

- Ehrenberger, W.:
  Softwareverifikation, Verfahren für den Zuverlässigkeitsnachweis von Software; Hanser 2002.

  Wenn es auch der Titel nicht vermuten läßt, es werden sowohl fehlervermeidende als auch fehlertolerierende Verfahren für zuverlässige Software diskutiert.

- Herrmann, D. S.:
  Software Safety and Reliability; IEEE Computer Society 1999.

  Guter Überblick über einschlägige (teilweise v. a. in den USA) übliche Standards, sowohl Spezifische für bestimmte Industriezweige als auch solche mit einer breiteren Allgemeingültigkeit.

- Leveson, N. G.:
  Safeware; Addison-Wesley 1995.

  Konzentriert sich auf sicherheitsorientierte Systeme.

- Lyu, M. R. (ed.):
  Software Fault Tolerance; Wiley 1995.

  Leider keine Monographie, sondern eine eher lose Sammlung von Themen-Blöcken, die irgendwie zur Software-Fehlertoleranz gehören.

- Schneeweiss, W.:
  Die Fehlerbaum-Methode; LiLoLe-Verlag 1999.

  "Das zentrale Problem dieses ganzen Bandes ist die Umwandlung der Booleschen Funktion phi des Fehlerbaumes in irgendeine Form, aus der man einigermassen leicht die Wahrscheinlichkeit des Wertes phi=1, der dem Systemausfall entspricht, bestimmen kann." - der Autor. Eine eindrucksvolle, aber optimistische Falldarstellung zahlreicher Fußangeln der Wahrscheinlichkeitsrechnung. Nebenwirkung: glaube (fast) keinem Tool zur automatischen Fehlerbaum-Analyse.