DRTS SS 2010

Summer Term 2010		Page no.	1 of 12
Faculty:	Graduate School, Information Technology	Semester:	ASM 2
Topic:	Distributed Real-Time Systems	Topic no.:	
Exam aids:	Written material, calculator	Time:	90 minutes

Name, Surname: Musterlösung

36 + 35 + 20

Question 1: (35 Minutes)

N

1.1 Give an example for an end-to-end protocol in the context of a distributed real-time system. Why would you have to use an end-to-end protocol at the interface between a computer system and the controlled object?

Answer:

Example: actuator which is observed by a sensor

Reason: Never trust an actuator (stuck value)

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Y

1.2 State three functional requirements for real-time systems.

Answer:

Data collection requirements
Direct digital control requirements
Man-machine interaction requirements

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Faculty:	Graduate School, Information Technology	Semester:	ASM2
Topic:	Selected Topics on Real-Time Systems	Topic no.:	
Exam aids:	Written material, calculator	Time:	90 minutes

1.3 An average car is operated about 400 hours per year. Compute the permissible MTTF if one out of one thousand cars may fail to provide the requested service throughout that year. Would such a car be considered a system with an ultrahigh reliability requirement? Please explain.

Answer:

Failure rate $\lambda = \dfrac{1 \text{ failure}}{400 \cdot 1000 \text{ hours}} = 2.5 \cdot 10^{-6}$

MTTF= $1/\lambda$ = 400.000 hours

4

1.4 Why can there be conflicts between reliability and maintainability? Please explain.

Answer:

Maintainability → more modular → more parts and interconnections → less reliable

4

1.5 Discuss the advantages and disadvantages of an event-triggered communication system vs. a time triggered communication system. What would you prefer for ultra-dependable systems, and why?

Answer:

Event triggered

+ flexibility
+ short latency at small loads
- temporal control outside of sphere of control of nodes
- not composable
- difficult to detect missing messages
- not predictable

Time triggered

+ composable
+ deterministic
+ just one interrupt (timer)
+ error detection based on a priori knowledge
+ constant latency independent of load conditions
- global time required
- less flexible

6

For ultra-dependable systems we need excellent error detection and deterministic behaviour. → time triggered communication system.

1.6 Explain the two failure modes of a clock.

Answer:

- Bad counter values (counter state error)
- Drift rate exceeds specified limits, i.e. counter runs too fast or too slow

4

1.7 How many binary digits (bits) would a digital counter need, if it was to directly measure a time interval of 1 hour with a digitization error of less than 10 nsec?

Answer:

Resolution: $10 \cdot 10^{-9}$ sec

For one hour: 3600 sec $\hat{=}$ 2^{12} (4096)

For one second: $\frac{1}{10 \cdot 10^{-9}}$ ~~≈ 10 nsec~~ $= 100 \cdot 10^{6}$

# of bits $= \frac{\ln 100 \cdot 10^{6}}{\ln 2} = 27$

=> | 12 bit | 27 bit | => $\underline{\underline{39 \text{ bits}}}$

12 bit: hour

27 bit: $100 \cdot 10^{6} \cdot 10$ nsec

4

1.8 Assume you need to measure a time interval with a precision of 10 nsec, where the start event and the end event can origin from different nodes, and the node clocks are synchronized to a global clock. What frequency must your node clocks at least have?

Answer:

$$(d_{obs} - 2g) < d_{true} < (d_{obs} + 2g)$$

$$2g \overset{!}{=} 10\,\text{nsec}, \quad g = 5\,\text{nsec} \qquad (\pm\ 10\,\text{nsec})$$

$$f = \frac{1}{g} = \frac{1}{5 \cdot 10^{-9}\,\text{sec}} = 200\,\text{MHz}$$

4

1.9 Given a latency jitter of 10 µsec, a resynchronization period of 100 msec, and a clock drift rate of 10^{-6} sec/sec, what precision can be achieved by the FTA algorithm in a system with 5 clocks where 1 clock could be malicious (µ(5,1) = 1,5)?

Answer:

$$\Pi(N, k, \varepsilon, \Gamma) = (\varepsilon + \Gamma) \cdot \frac{N-2k}{N-3k} =$$

$$(\varepsilon + 2 * \rho \cdot R_{int}) \cdot \left(\frac{5-2}{5-3}\right) =$$

$$\left(\varepsilon + 2 \cdot 10^{-6}\,\frac{\text{sec}}{\text{sec}} \cdot 0{,}1\,\text{sec}\right) \cdot 1{,}5 =$$

$$\left(10 \cdot 10^{-6} + 2 \cdot 10^{-6} \cdot 0{,}1\right) \cdot 1{,}5 = \quad 1{,}53 \cdot 10^{-5}\,s = \underline{\underline{15{,}3\,\mu s}}$$

4

Question 2: (35 Minuten)

2.1 Please explain why it is difficult to determine the WCET of processes in a hard-real time system. State three methods that have been advised to determine WCET, and discuss their limitations.

Answer:

Difficulties:

- finding critical path of a program
- Interrupt handling changes WCET, not deterministic
- Preemption by other tasks in OS
- pipelining and caching
- compiler dependencies

6

Methods: 5

1. Source code (static) analysis. It requires complicated tools which take into account the generated object code and caching/pipelining
2. Measurement. But how do we ensure that we got the critical path?
3. Microarchitecture timing analysis. Only works for simple microcomputer architectures.

2.2 What is an observation in the context of real-time systems? Explain the two major types of observations and discuss their advantages and disadvantages.

Answer:

Observation: state information of RT entity at particular point in time: $\langle name, t_{obs}, value \rangle$

State observation: value is state of RT entity at t_{obs}. Value is periodically observed.

- \+ reliable, even if an observation gets lost
- \- more data transfers, even if value does not change

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Event observation: change of states are observed. The t_{obs} is only an approximation of the event time

- \+ data transfer only in case of changes
- \- problem if message gets lost

2.3 Calculate the action delay in a distributed system with the following parameters:
dmax=10msec, dmin=2msec,
and a) no global time available, granularity of local time is 50 µsec
and b) global time with granularity of 100 µsec.

Answer:

a) action delay $= 2 d_{max} - d_{min} + g$

$= 18.05$ msec

b) action delay $= d_{max} + 2g$

$= 10.2$ msec

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2.4 What kind of redundancy would you employ if you needed to detect errors caused by independent software faults and by transient and permanent physical hardware faults?

Answer:

Diverse software on diverse hardware

- different software versions ~~remove~~ detect design errors
- diverse hardware protects against hardware faults

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2.5 What is triple modular redundancy (TMR)?

Answer:

When an FTU is composed of three nodes and a voter. Even if a node does not fail silent, the voter makes sure that the majority output value is the only output.

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2.6 Fault tolerance can be implemented by two fail-silent nodes or by Triple Modular Redundancy (TMR). Discuss the advantages and disadvantages of each approach.

Answer:

Two fail-silent nodes:

+ just two nodes, compared to three plus voter
+ correct result or no result
- idempotency required (duplicated messages)
- fail-silent may require additional hardware?

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TMR:

+ works even in case of value errors at CNI
+ just one result, no idempotency
- cost, three nodes required
- voter requires hardware or computing time

Question 3: (20 Minuten)

2

3.1 Given a bandwidth of 1 MBits/sec, a channel length of 100 m and a message length of 64 bits, what is the limit of the protocol efficiency that can be achieved at the media access level of a bus system?

Answer:

bit length of channel $= \frac{100\,m}{0{,}2\,m/sec} = 500\,ns \hat{=} 0{,}5\,bit$

data efficiency $= \frac{\text{mess. length}}{\text{mess. length} + bl} = \frac{64\ bit}{64{,}5\ bit} = \underline{\underline{99{,}2\%}}$

4

3.2 Explain the role of the three time-outs in the ARINC 629 protocol. Is it possible for a collision to occur on an ARINC 629 bus?

~~2~~ 2

Answer:

SG = synchronization gap

TG = terminal gap

TI = transmit interval

It is not possible for collisions to occur.

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3.3 What mechanism helps to ensure the fail-silence of a TTP controller in the temporal domain?

N

Answer:

This is the task of the bus guardian (BG), a hardware device.

3

N

3.4 Estimate the average and worst-case response time of a TTP/C system with 8 FTUs, each one consisting of two nodes that exchange messages with 10 data bytes on a channel with a bandwidth of 10 MBit/s. Assume that the interframe gap is 8 bits.

Answer:

TTP/C frame: 4 bits header + 80 bits data + 16 bits CRC
= 100 bits

8 FTUs ≙ 16 nodes → 16 messages

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A cluster cycle / TDMA round thus consists of
16 · (mess. length + interframe gap)
= 16 · 108 Bits = 1728 Bits

Average response time = 0,5 TDMA rounds

$= \frac{1728 \text{ bits}}{2 \cdot 10 \text{ Mbits/sec}} = \underline{\underline{86.4 \mu s}}$

Worst case response time = 1 TDMA round = $\underline{\underline{172{,}8 \mu s}}$

3.5 Explain the difference between polling and sampling.

Answer:

In sampling and polling sensor values are regularly transferred to a computer.

Sampling: memory element is placed at the sensor
→ no loss of information when computer goes down
→ transient disturbances on transmission line have no effect

Polling: memory element is placed at the computer.
→ information loss at computer power down
→ transient disturbances are stored in memory element

4

DRTS SS 2011

University of Applied Sciences Esslingen

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Faculty:	Graduate School, Information Technology	Semester:	ASM 2
Topic:	Distributed Real-Time Systems	Topic no.:	
Exam aids:	Two DIN-A4 sheets, calculator	Time:	90 minutes

Name, Surname: Musterlösung SS 11

Question 1: (35 Minutes)

1.1 Sketch a simple model of a real-time system and partition it into three important parts. Name each cluster and the interfaces between them.

Answer:

see slide 1.3

2 +1

1.2 What is the difference between a real-time image and a real-time entity?

Answer:

A real-time entity is a significant state variable of a real-time system.
A real-time image gives information about a real-time entity at a certain point in time.
It is the result of an observation of a real-time entity.
It is valid if it is an accurate representation of the RT entity in the temporal and value domain.

3

1.3 Hard disk drives are often advertised with very high MTBFs. Some manufacturers have switched to a different specification, the annual failure rate (AFR). The AFR is defined as that percentage of a large number of disc drives that exhibit a defect when continuously being run for a year.

What is the MTBF for a hard disc drive when the observations of the last year gave an AFR of 0.73%, that is 0.73% of all disc drives that had been running continuously for a year exhibited a defect?

Answer:

1 year $\hat{=}$ 365 · 24 h = 8760 h

$$MTBF = \frac{8760}{0{,}73\%} = 1.200.000\ h$$

MTBF= 1.200.000 hours

3

1.4 Is real-time computing equivalent to fast computing? What is the main goal in the design of real-time computing systems? Please discuss briefly.

Answer:

No, it is computing within timing constraints

Main goals:

- low latency and minimal jitter
- predictable and deterministic behaviour
- composability
- flexibility
- error detection support
- cost

~~4~~ 3

1.5 The start of an injection in a modern combustion engine must be controlled to better than 1°, to adhere to environmental standards. The idle motor speed of an engine is 800 rpm, the maximum rate is 4500 rpm. The maximum change in motor speed in case of a load change is 1500 rpm/sec.

a) Compute the maximum temporal accuracy for the start of the injection.

b) Compute for a one-cylinder four cycle engine at constant rpm the minimum time that is available for the computation of the injection time. A four cycle engine needs to inject only every other full crankshaft turn. Assume that there are no other processes running on the computer calculating the injection time.

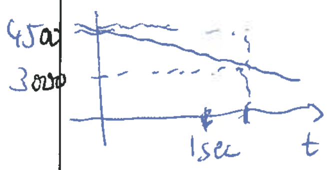
c) When the injection time is calculated early, it can become imprecise due to a change in rpm during this time. Compute how far in advance the injection time can be calculated without violating the 1° limit, assuming a maximum motor speed change. Assume for your calculation that the computation doesn't take any time at all.

Answer:

a) maximum temporal accuracy = $\frac{1^\circ}{360^\circ} \cdot \frac{1}{4500/60} \cdot s = 37\,\mu s$ 2

2 * time for one round

b) minimum computation time = $\frac{2 \cdot 60}{4500} \cdot s = 27\,ms$ 2



$\mathcal{M}(t) = \mathcal{M}_0 + \Delta\mathcal{M} \cdot t$

$\alpha = 360^\circ \cdot \int \mathcal{M}(t)\,dt$

when $\mathcal{M}(t) =$ const:

$\alpha = 360^\circ \cdot \mathcal{M}_0 \cdot t$

otherwise: $\alpha = 360^\circ \left[\mathcal{M}_0 \cdot t + \underbrace{\Delta\mathcal{M} \cdot \frac{t^2}{2}}\right]$

error term, should be less than 1°

$\Rightarrow$ $1^\circ > 360^\circ \cdot \Delta\mathcal{M} \cdot \frac{t^2}{2}$

$\Rightarrow \sqrt{\frac{1}{360} \cdot \frac{2 \cdot 60}{1500} s^2} \Rightarrow t = 14{,}9\,ms$

c) maximum advance computation time = 5

1.6 Explain the three different types of orders with regard to alarms in a distributed real-time system. Which of the orders implies another?

Answer:

Temporal order: order of ~~events~~ alarms along a global time line

Causal order: ~~temporal order~~ cause and effect

Delivery order: order in which alarms are received by a receiver

Causal order implies temporal order

3

1.7 How can a sparse time base help to avoid agreement protocols?

Answer:

In a sparse time base events are allowed to occur only during certain predefined intervals. Thus there is no need to make sure via an agreement protocol that the temporal event order at the receiver corresponds to the temporal order at the sender. Events are either simultaneous or Δ apart.

3

1.8 Assume you have node clocks running at a frequency of 100 MHz. What precision can you achieve when measuring a time interval, where the start event and the end event can origin from different nodes, and the node clocks are synchronized to a global clock?

Answer:

For observation of time interval

$$d_{obs} - 2g < d_{true} < d_{obs} + 2g$$

$$g = \frac{1}{100 \cdot 10^6} s = 10\,ns$$

Hence: precision $= \pm 2g = \underline{\pm 20\,ns}$

3

1.9 Given a resynchronization period of 500 msec, and a clock drift rate of 10^{-6} sec/sec, what latency jitter can be tolerated to achieve a precision of 20 µsec using the FTA algorithm in a system with 5 clocks where 1 clock could be malicious (µ(5,1) = 1,5)?

Answer:

$R_{int} = 500\,ms$; $\rho = 10^{-6}$ $\quad \frac{N-2k}{N-3k}$ k Byzantine faults

$\Pi = (\varepsilon + \Gamma)\mu(5,1) \Rightarrow 20\mu s = (\varepsilon + 2 \cdot \rho \cdot R_{int}) \cdot 1{,}5$

$$\Rightarrow \varepsilon = \frac{\Pi}{\mu} - 2\rho \cdot R_{int} = \frac{20 \cdot 10^{-6} s}{1{,}5} - 2 \cdot 10^{-6} \cdot 500 \cdot 10^{-3} s$$

$$\varepsilon = 1{,}23 \cdot 10^{-5} s = \underline{12{,}3\,\mu s}$$

5

Question 2: (35 Minuten)

2.1 Please explain the difference between a simple task (S-task) and a complex task (C-task).

Answer:

Simple task	Complex task
- no explicit synchron. points	- Can have explicit synch. points
- WCET depends only on task itself (negl. inter-rupts)	- WCET is dependent on other tasks
- Scheduling is predictable	

6

2.2 What is a history state? Please explain with an example.

Answer:

- The history state

5

Y

2.3 Calculate the action delay in a distributed system with the following parameters:
dmax=20msec, dmin=5msec,
and a) no global time available, granularity of local time is 100 µsec
and b) global time with granularity of 500 µsec.

Answer:

a) no global time: $g_l = 100 \cdot 10^{-6}$ sec

action delay $= 2 \cdot d_{max} - d_{min} + g_l$

$= 40$ msec $- 5$ msec $+ 0{,}1$ msec

$= \underline{35{,}1 \text{ msec}}$

b) global time: $g = 500 \cdot 10^{-6}$ sec

action delay $= d_{max} + 2g$

$= 20$ msec $+ 1$ msec

$= \underline{21 \text{ msec}}$

6

Y

2.4 When is a set of nodes replica determinate?

Answer:

A set of nodes is replica determinate when all the replicated nodes visit the same externally visible h-state and produce the same output at intervals that are at most d apart

For proper implementation of a fault tolerant system replica determinate nodes are essential

The parameter d determines the period within which a failed node can be replaced by a replicated node

→ see slide 5.20

6

2.5 What is state estimation?

Answer:

see slide 5.13

6

2.6 Explain the terms fault, error, an failure.

Answer:

see slide 6.3

6

Question 3: (20 Minuten)

N

3.1 Given a bandwidth of 10 MBits/sec, a channel length of 200 m and a required protocol efficiency of 90%, what is the maximum message length in bit that can be implemented by the media access level of a bus system?

Answer:

$$\text{data eff.} = \frac{ml}{ml + bl} \rightarrow (ml + bl) \cdot de = ml$$

$$\rightarrow ml = \frac{de \cdot bl}{1 - de} = \frac{de}{1-de} \cdot \frac{\text{chlength} \cdot 10\,\text{MBit/s}}{200.000 \cdot 10^3\,\text{m/s}} = 90\,\text{bit}$$

5

Y

3.2 What mechanism can lead to thrashing? How should you react in an event-triggered system if thrashing is observed?

Answer:

Retry-mechanism of PAR-protocol increases load which in turn can lead to even more retries.

Remedy: observation of # of retries / drop in throughput and exertion of back pressure (implies there is some mechanism) to exert flow control other than the PAR acknowledge messages)

4

3.3 How can one distinguish between a Fireworks byte and a data byte in the TTP/A protocol?

N

Answer:

1) Fireworks byte has odd parity while data bytes have even parity
2) Spacing after fireworks byte is larger than spacing between data bytes.

3

3.4 Calculate the data efficiency of a TTP/A system that consists of 5 nodes where each node sends periodically a two byte message (user data). Assume that the intermessage gap between the Fireworks byte and the first data byte is 4 bitcells, and the intermessage gap between two successive data bytes is two bitcells. The gap between the end of one round and the start of the next round is 6 bitcells.

N

Answer:

No. of bits per byte message: 8bit data + 1 start bit + 1 stop bit + 1 parity = 11 bit

No. of bytes in a TTP/A round: 5 nodes × 2 bytes = 10 bytes

Inter frame gap (Fireworks - Data) = IFG1 = 4 bits
Inter frame gap (Data - Data) = IFG2 = 2 bits
Inter round gap = IRG = 6 bits

4 +1

Total length of round = 10 bytes data × 11 bits
+ 1 byte fireworks × 11 bits
+ 1 × IFG1
+ 9 × IFG2 (between the 10 data bytes)
+ 1 × IRG
= 149 bits

Total data bits = 10 × 8 bits = 80 bits

$$\eta = \frac{80}{149} \cdot 100 = 53.7\%$$

3.5 Explain three major problems that we encounter in interrupt-driven software.

Answer:

3