2014-10-31

**Written exam in EDA387/DIT663 Computer Networks 2014-10-31. Exam time: 4 hours.**

*Means allowed: Nothing except paper, pencil, pen and English - xx dictionary.*

*Examiner:* Elad Michael Schiller, phone: 073-6439754
Note that student questions can be answered only by phone.

| | | | |
|---|---|---|---|
| *Credits:* | 30-38 | 39-47 | 48-Max |
| *Grade:* | 3 | 4 | 5 |
| Grade (GU) | G | G | VG |

1. The answer must be written in English (even for Swedish students). Use proper grammar and punctuation.
2. All answers need to be motivated, unless otherwise stated. Correct answers without motivation or with wrong motivation will not be given full credit.
3. Answer concisely, but explain all reasoning. Draw figures and diagrams when appropriate.
4. **4.** Write clearly. Unreadable or hard-to-read handwriting will not be given any credit.
5. **5.** Do not use red ink.
6. **6.** Solve only one problem per page.
7. **7.** Sort and number pages by ascending problem order.
8. **8.** Anything written on the back of the pages will be ignored.
9. Do not hand in empty pages or multiple solutions to the same problem. Clearly cross out anything written that is not part of the solution.

**Question 1 DNS (8 points)**

Please answer each of the sub-questions given below separately and by using **DNS-terminology and concepts**.

**1a. (4p)** Mention and describe the **meaning and contents** of at least **four** commonly used Resource Records (name, type, value) in the DNS database.

ANSWER: Please refer to the DNS-lecture slide 17-18 and the course books.

The following is short explanation of some DNS Resource Records.

**MX: Mail eXchanger,** the given name is **domain name** and the returned value is **hostname of mail server** associated with domain name.

**NS: Name Server**, the given name is **domain name** and the value is **hostname of authoritative name server** responsible for this domain.

**A: Address for IPv4**, the given name is **hostname** and the returned value is **IPv4 Address**

**CNAME: Canonical NAME,** the given name is **alias name** and the returned value is the **canonical (real) name.**

**AAAA: Address for IPv6**, the given name is **hostname** and the returned value is **IPv6 Address**

**1b. (4p)** Suppose that you are using the Chalmers network to connect your laptop to the Internet. Suppose also that you want to access the web site www.tue.nl for the **first** time. Explain **how and why** DNS will be involved immediately after entering the name of the site in your browser. Assume that there is **no** cached DNS-information (about this site), anywhere in Chalmers network. The answer should, specifically and technically, explain the necessary operation, including:

- the interaction and communication between the different DNS resolvers and servers,
- the protocols and messages used, and
- the final outcome.

ANSWER: Please refer to the DNS-lecture slides 20-21 and the course books.

The following is short answer:
- The web browser needs the IP address of the server before initializing the TCP connection with the web server. Initial contact begins with local name server at Chalmers (host can learn address of DNS server from DHCP). The DNS-client starts with sending DNS-query to the local server in order to recursively resolve the hostname www.tue.nl into IP address. (1) The local server queries a root-server to find nl TLD servers. (2) The local server queries nl TLD-server to find tue.nl auth. Servers. (3) The local server queries one authoritative DNS-server to get IP address(es) for www.tue.nl.

Local server caches answers (owner specifies cache timeout by including TTL in answer). The local server will reply to the DNS client by sending the answer including the IP address(es) of the server of the site.

DNS query and reply messages are transported in UDP segments.

---

**Question 2 IPv6 Addresses (6 points)**

These three addresses are given with IPv6 representation:

(i) `2001:6b0:2:10::1`
(ii) `FF02::1:ff6c:14dd`
(iii) `FE80::20c:f1ff:fe6c:14dd`

Please answer the following sub-questions in relation to the above addresses.

**2a. (1p)** Decompress and rewrite each of the given addresses showing all hexadecimal digits.

(i) `2001:06b0:0002:0010:0000:0000:0000:0001`
(ii) `FF02:0000:0000:0000:0000:0001:ff6c:14dd`
(iii) `FE80:0000:0000:0000:020c:f1ff:fe6c:14dd`

**2b. (2p)** What is the "type" of each of these IPv6 addresses? Explain what each type does imply.

(i) `2001:6b0:2:10::1 UNICAST`
(ii) `FF02::1:ff6c:14dd    MULTICAST`
(iii) `FE80::20c:f1ff:fe6c:14dd UNICAST`

**2c. (1p)** Which of the given addresses can**not** be used as valid source address in IPv6 packet? Explain why?

(ii) `FF02::1:ff6c:14dd    MULTICAST (group or set of interfaces, used only as destination address)`

**2d. (2p)** What is the "scope" of each of these IPv6 addresses? Explain what each scope does imply.

(i) 2001:6b0:2:10::1 GLOBAL
(ii) FF02::1:ff6c:14dd LINK-LOCAL
(iii) FE80::20c:f1ff:fe6c:14dd LINK-LOCAL

IPv6 addresses are identifiers that are assigned to interfaces and **sets** of interfaces. The scope identifies the location of the receiver(s) of the IPv6 packets. It specifies in which part of the network the address is valid and where the packets are allowed or not to be routed to the destination. The scope is recognized by the prefix of the address and it can be **local** or **global**.

---

**Question 3 ICMPv6 (8 points)**

**3a. (2p)** What is the **main** purpose of IPv6 Neighbor Discovery? Explain **clearly** the operation.

**3b. (2p)** What are the messages deployed in IPv6 Neighbor Discovery? Explain how these messages will be encapsulated and addressed in layer-2 and layer-3 PDUs (i.e. packets and frames).

Short answer for (3a) and (3b):

The main purpose of IPv6 Neigbour Discovery is to obtain the link-layer address of a neighbour, using ICMPv6 neighbour solicitation and neighbour advertisement messages sent in IPv6 packets with multicast to the solicited-node.

For complete answer please refer to slides 44-45 in IPv6 handouts.

**3c. (4p)** What is the purpose of sending the message "Router Advertisement"? What are the **most** important parts of information does it contain? Explain at least **three** and how they are useful for IPv6 nodes.

Short explanation:

The stateless autoconfiguration of IPv6 nodes includes automatic configuration of unicast link-local and global addresses using 64 bits interface identifier. A node can use the unicast link-local IPv6 addresses to send ICMPv6 router solicitation message to get prefix information in an ICMPv6 router advertisement message from the local router. The prefix information can then be used node to automatically configure its global address.

For complete answer please refer to the slides 47-49 in IPv6 handouts.

---

**Question 4 (6 points) Socket API: `select()`**

Each of the following parts of a program contains a flaw. Identify and describe the flaw in a few short sentences or points. You do not have to correct the flaw; you should just find and describe it! (Note: you're not looking for, e.g., syntax errors. Find conceptual flaws in the program.)
Hint: The program uses `select()` and they are supposed to be non-blocking. Consider which operations can actually block the processes that execute these programs.
The following program accepts new connections using the `listenfd` socket. The first byte sent by a client is expected to be an 8 bit ID.

- You may assume that the `handle_*_error()` methods do something sensible.
- The helper method `register_client(client, id)` verifies the client ID is acceptable and if that is the case, enters the client into a global list. Otherwise it closes the connection.
- The method `add_client_sockets_to_readfds()` properly adds all active clients in the global list to the readfds. It returns the largest socket number it encounters.
- `handle_registered_clients()` handles clients that are ready to send data according to `readfds`, and removes clients that close their associated connections from the global list. No data is ever sent to the clients, the program only receives and processes data sent to it.

```
/* includes, declarations, etc. */
int main() {
        int listenfd = -1;
        /* initialization code, such as setting up a listening socket on listenfd, has been omitted – this is not the error you're looking for */
                while( 1 ) {
                        fd_set readfds; // initialize read set
                        FD_ZERO( &readfds );
                        int maxfd = add_client_sockets_to_readfds( &readfds );
                        FD_SET( listenfd, &readfds );
                        if( listenfd > maxfd ) maxfd = listenfd;
                        int ret = select( maxfd+1, &readfds, 0, 0, 0 ); // call select
                        if( -1 == ret ) handle_select_error();
                        // is there a new client waiting?
                        if( FD_ISSET( listenfd, &readfds ) ) {
                                sockaddr_in clientAddr;
                                socklen_t clientAddrLen = sizeof(clientAddr);
                                int client = accept( listenfd,
                                        (sockaddr*)&clientAddr,
                                        &clientAddrLen
                                );
                                if( -1 == client ) handle_accept_error();
                                // receive 8bit client ID
                                unsigned char id;
                                int ret = recv( client, &id, sizeof(id), 0 );
                                if( 0 == ret ) {
                                        close( client );
                                        continue;
                                }
                                if( -1 == ret ) handle_recv_error();
                                // register client
                                register_client( client, id );
                        }
                        handle_registered_clients(&readfds);//handle registered clients
                }
                return 0;
        }
```

**Question 5 (8 points)**

We learned in class a self-stabilizing algorithm for BFS spanning tree construction, see the code below. Explain how transient faults can cause the system to output an error. We define a *floating distance* in configuration c, as a value stored in $r_{ij}.dis$ that is smaller than the distance of $p_i$ from the root, where *dis* is the distance field of the registers.

```
Root: do forever
        for $m$ := 1 to $\delta$ do write $r_{im} := \langle 0,0 \rangle$
    od
Other: do forever
    for $m$ := 1 to $\delta$ do $lr_{mi}$ := read($r_{mi}$)
    $FirstFound := false$
    $dist := 1 + min\{lr_{mi}.dis \mid 1 \le m \le \delta\}$
    for $m$ := 1 to $\delta$
    do
        if not $FirstFound$ and $lr_{mi}.dis = dist - 1$
            write $r_{im} := \langle 1, dist \rangle$
            $FirstFound := true$
        else
            write $r_{im} := \langle 0, dist \rangle$
    od
od
```

Prove that for every $k > 0$ and for every configuration that follows $\Delta + 4k\Delta$ rounds, it holds that:

- If there exists a floating distance, then the value of the smallest floating distance is at least $k$.
- The value in the registers of every processor that is within distance $k$ from the root is equal to its distance from the root.

**Proof.** Note that in every 2Δ successive rounds, each processor reads the registers of all its neighbors and writes to each of its registers. We prove the lemma by (1) induction over k.

**Base Case: Proof for k=1.** Distances stored in the registers and internal variables are non-negative; thus the value of the smallest floating distance is at least 0 in the first configuration. During the first 2Δ rounds, each non-root processor $p_i$, computes the value of the variable *dist* (line 7). The result of each such computation must be (2) greater than or equal to 1. Let $c_2$ be the configuration reached following the first computation of the value of *dist* by each processor.

Each non-root processor writes to each of its registers the computed value of *dist* during the 2Δ rounds that follow $c_2$. Thus, in every configuration that follows the first 4Δ rounds there is no non-root processor with value 0 in its registers. The above proves (3) assertion 1.
To prove (4) assertion 2, note that the root repeatedly writes the (5) distance 0 to its registers in every (6) Δ rounds. Let $c_1$ be the configuration reached after these (7) Δ rounds. Each processor reads the registers of the root and *then* writes to its own registers during the 4Δ rounds that follow (8) $c_1$. In this write operation the processor assigns (9) 1 to its own registers. Any further read of the root registers returns the value (10) 0; therefore, the value of the registers of each neighbor of the root is (11.1) 1 following the first Δ + 4Δ rounds. Thus, (11.2) assertion 2 holds as well.

**Induction Step.** We assume correctness for (12) $k \geq 0$ and prove for k + 1. Let $m \geq k$ be the smallest floating distance in the configuration $c_{4k}$ that follows the first Δ + 4*k*Δ rounds. During the 4Δ rounds that follow $c_{4k}$, each processor that reads *m* and chooses *m* as the smallest value assigns (13) $m + 1$ to its distance and writes this value. Therefore, the smallest floating distance value is $m + 1$ in the configuration $c_{4(k+1)}$. This proves (14) assertion 1.

Since the smallest floating distance is (15) $m \geq$ (or$>$) $k$, it is clear that each processor reads the distance of a neighboring processor of distance *k* and assigns (16) $k + 1$ to its distance. ■

**Question 6 (4 points)**

6.a **(1 p)** The set of legal executions, *LE*, includes all executions in which the system behaves according to the required properties (and no other execution). Use the notation *LE* to define the term *safe configuration*. We say that configuration *c* is *safe* if every exaction *R* (run) that starts from *c* is a legal execution, i.e., *R* is in *LE*.

6.b **(3 p)** We learned in class a non-stabilizing algorithm for synchronous consensus, see the code below. Explain how transient faults can cause the system to output an error.

```
initialization
    $pulse_i := 0$
    $O_i := I_i$
while $pulse_i \leq D$ do
    upon a pulse
        $pulse_i := pulse_i + 1$
        send ($O_i$)
        forall $P_j \in N(i)$ do receive ($O_j$)
        if $O_i = 0$ and $\exists P_j \in N(i) \mid O_j = 1$ then
            $O_i := 1$
```

This algorithm is not a self stabilizing algorithm

For example, any execution that starts in a system configuration in which the value of at least one output variable is 1, the program counter of every processor is greater than 3, and in which there exists no input variable with the value 1 never reaches a safe configuration. The reason is that no processor assigns 0 to the output variable following the execution of line 3 of the code.

**Question 7 (6 points)**

Please find below a self-stabilizing algorithm for leader election, where *N* is an upper bound on the number of processors in the system.
7.a **(2 p)** Please define the safe configuration of the algorithm. Make sure that you consider all variables and shared registers.

For all $p_i$ in $P$, $leader_i = \min(\{ID(j)\}: p_j \text{ in } P)$
The variables $dis_i$ encodes a BFS tree that is rooted at $leader_i$.
The variables $leader_i[]$ and $dis_i[]$ refer to the respective neighbours values.
The variables candidate and distance are not part of the processor state because they constructed and initiated at the start of the loop and destroyed at its end.

7.b **(4 p)**. Suppose the system execution, *R*, starts in a safe configuration, *c*. Let $a_i$ be a step that processor *pi* takes immediately after *c* and just before c'. Please show that c' is safe.

```
do forever
    $\langle candidate, distance \rangle = \langle ID(i), 0 \rangle$
    forall $P_j \in N(i)$ do
        begin
            $\langle leader_i[j], dis_i[j] \rangle :=$ read$\langle leader_j, dis_j \rangle$
            if $(dis_i[j] < N)$ and $((leader_i[j] < candidate)$ or
                $((leader_i[j] = candidate)$ and $(dis_i[j] < distance)))$ then
                    $\langle candidate, distance \rangle := \langle leader_i[j], dis_i[j] + 1 \rangle$
        end
    write $\langle leader_i, dis_i \rangle := \langle candidate, distance \rangle$
od
```

**Question 8 (8 points)**

We learned in class several algorithms for self-stabilizing clock synchronization. Please find below the code of a couple of them, which we call: converge-to-the-min and -max.

Converge-to-the-max

```
upon a pulse
    forall $P_j \in N(i)$ do send $(j, clock_i)$
    $max := clock_i$
    forall $P_j \in N(i)$ do
        receive$(clock_j)$
        if $clock_j > max$ then $max := clock_j$
    od
    $\boxed{clock_i := (max + 1) \bmod ((n+1)d+1)}$
```

Converge-to-the-min

```
upon a pulse
    forall $P_j \in N(i)$ do send $(j, clock_i)$
    $min := clock_i$
    forall $P_j \in N(i)$ do
        receive$(clock_j)$
        if $clock_j < min$ then $min := clock_j$
    od
    $\boxed{clock_i := (min + 1) \bmod (2d+1)}$
```

8.a **(2 p)** What do the constants *d* and *n* stand for?
We denote by d the network diameter and by n the number of nodes in the networks.

8.b **(1 p)** Please compare these two algorithms with respect to their scalability property. Which one scales better? Why?

The converge-to-the-min algorithm does not depend on the number of nodes in the system. Since in practice the network diameter grows much slower than the number of nodes, the same number of bits use for the clock counter in the converge-to-the-min algorithm would be good for a much larger network than the converge-to-the-max.

8.c **(1 p)** Please compare these two algorithms with respect to the service provided to the application layer. Which one is easier to work with? Why?

The disadvantage that converge-to-the-min algorithm has over the converge-to-the-max algorithm is that during convergence, the clock will adjust backwards. That can be very confusing for the program at the application layer (or any other layer).

8.d **(4 p)** Please complete the correctness proof of the algorithm converge-to-the-min

Suppose that no processor (1) has a clock the warps around to the zero value during the first (2) d pulses. Then we can use simple (3) induction arguments (as used for the unbounded clock synchronization algorithm) to show that synchronization is achieved. Otherwise, a processor (4) there is at least one processor that its clock value warps around to the zero value and assigns zero to it during the first (5) d pulses. Therefore, (6) d pulses after this point a configuration *c* is reached, such that there is no clock value greater than (7) d : the first (8) case holds.

## Digital Clock Sync – Bounded version (min)

- The Boundary M = 2d+1
- Why is this algorithm correct?
  - If no processor assigns 0 during the first d pulses – sync is achieved (can be shown by simple induction)

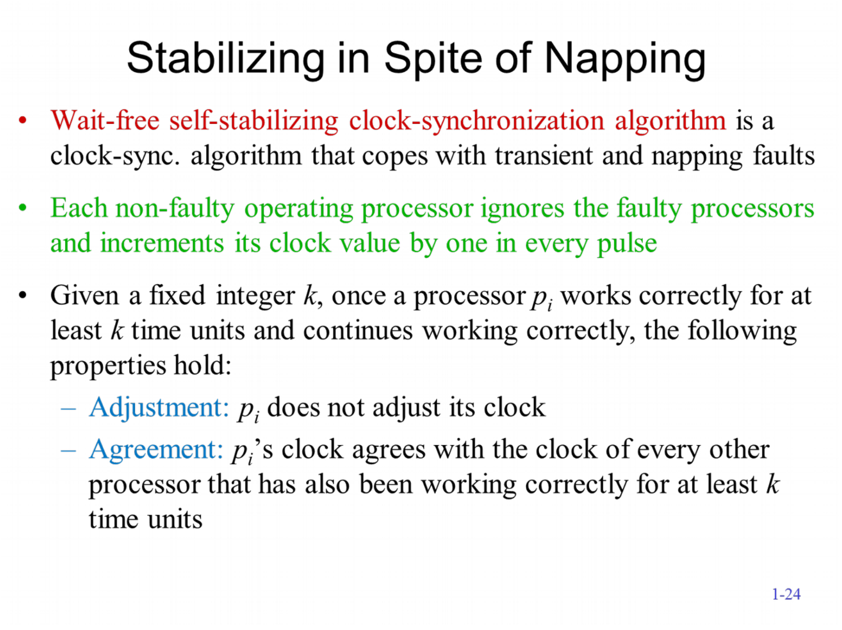
  Else
  - A processor assigns 0 during the first d pulses,
    - d pulses after this point a configuration c is reached such that
      - there is no clock value greater than d: the first case holds

```
upon a pulse
    forall $P_j \in N(i)$ do send $(j, clock_i)$
    $min := clock_i$
    forall $P_j \in N(i)$ do
        receive($clock_j$)
        if $clock_j < min$ then $min := clock_j$
    od
    $clock_i := (min + 1) \bmod (2d + 1)$
```

**Question 9 (6 points)**

9.a **(2 p)** Define the task of wait-free self-stabilizing clock synchronization. Given a fixed integer *k*, once a processor $p_i$ works correctly for at least *k* time units and continues working correctly, the following properties hold:

- Adjustment: $p_i$ does not (1) does not adjust its clock.
- Agreement: $p_i$'s clock (2) agrees with the clock of (3) every other processor that has also (4) been working correctly for at least *k* time units.



## Stabilizing in Spite of Napping

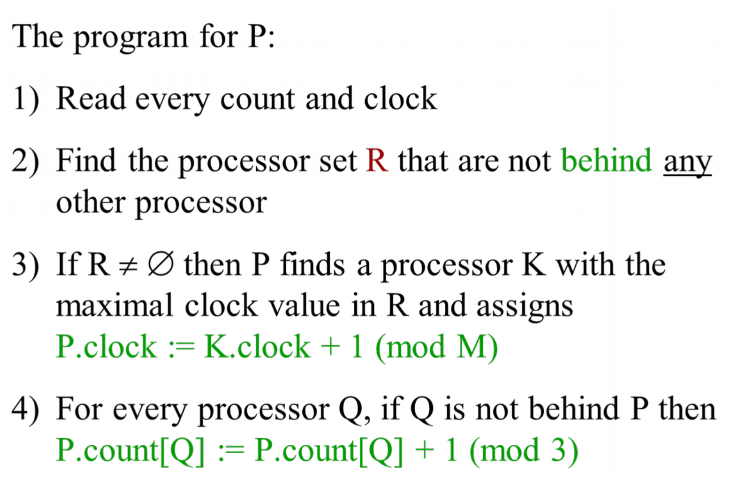
- Wait-free self-stabilizing clock-synchronization algorithm is a clock-sync. algorithm that copes with transient and napping faults
- Each non-faulty operating processor ignores the faulty processors and increments its clock value by one in every pulse
- Given a fixed integer *k*, once a processor $p_i$ works correctly for at least *k* time units and continues working correctly, the following properties hold:
  - Adjustment: $p_i$ does not adjust its clock
  - Agreement: $p_i$'s clock agrees with the clock of every other processor that has also been working correctly for at least *k* time units

1-24

9.b **(4 p)** We learned in class an algorithm for wait-free self-stabilizing clock synchronization for the fully connected graph, please find below its code. Each processor P has the following two variables: (1) P.clock ∈{0… M-1} and (2) ∀ Q : P.count[Q] ∈ {0,1,2}. We say that processor P is behind Q if P.count[Q]+1 (mod 3) = Q.count[P].

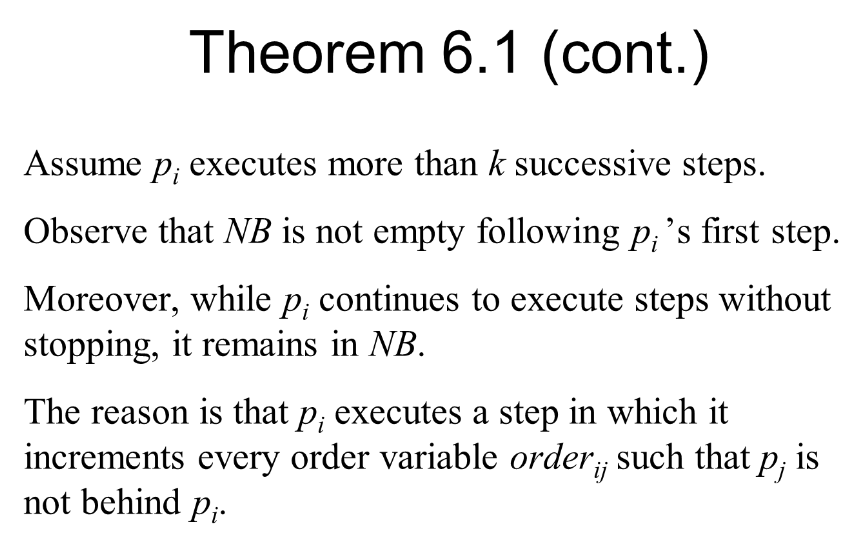
Suppose the processor P executes more than k=2 successive steps. Show that the set *NB*, which is *R* in the code to the right, is not empty following P's first step.

The reason is that $p_i$ executes a step in which it increments every order variable $order_{ij}$ such that $p_j$ is not behind $p_i$.



The program for P:

1) Read every count and clock
2) Find the processor set R that are not behind any other processor
3) If R ≠ ∅ then P finds a processor K with the maximal clock value in R and assigns P.clock := K.clock + 1 (mod M)
4) For every processor Q, if Q is not behind P then P.count[Q] := P.count[Q] + 1 (mod 3)



## Theorem 6.1 (cont.)

Assume $p_i$ executes more than $k$ successive steps.

Observe that $NB$ is not empty following $p_i$'s first step.

Moreover, while $p_i$ continues to execute steps without stopping, it remains in $NB$.

The reason is that $p_i$ executes a step in which it increments every order variable $order_{ij}$ such that $p_j$ is not behind $p_i$.

**Question 10 (8 points)**

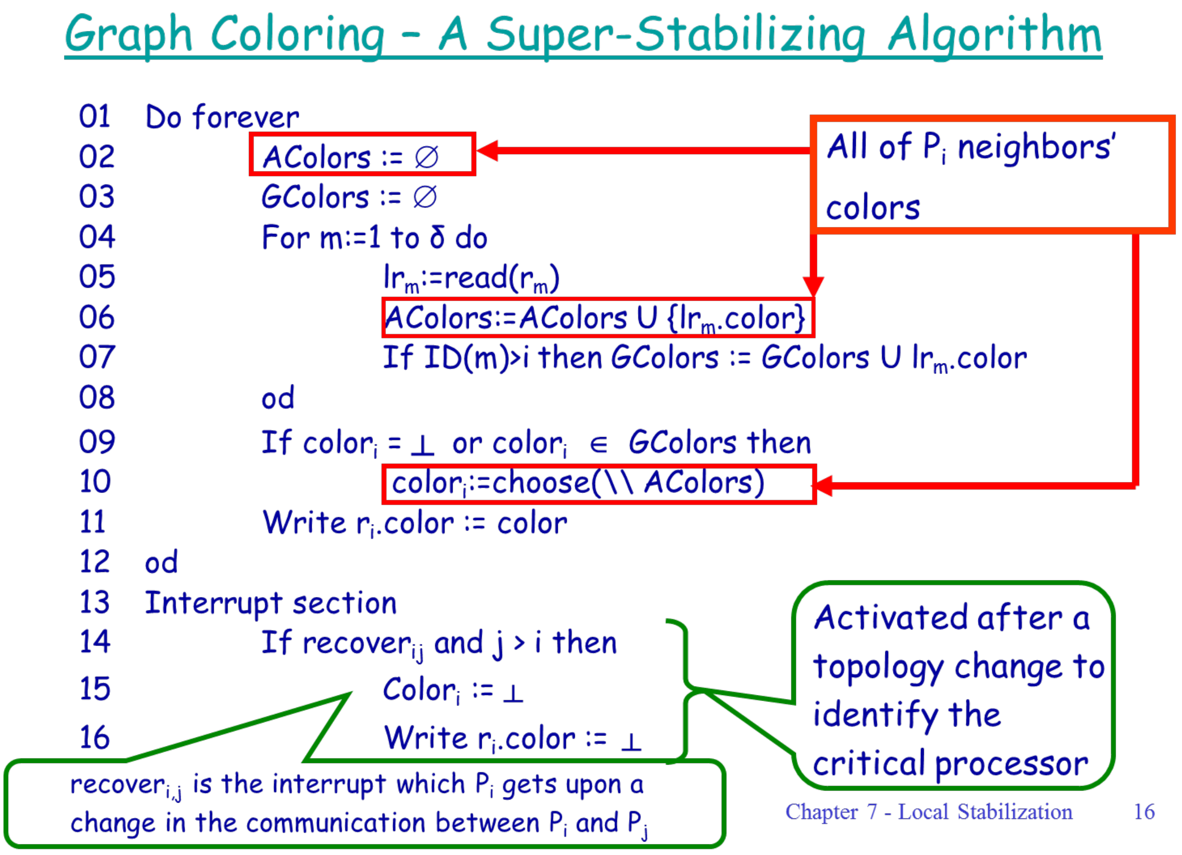
10.a **(2 p)** Define the task of vertex coloring.

The coloring task is to assign a color value to each processor, such that no two neighboring processors are assigned the same color. Your answer may also include: Minimization of the colors number is not required. The algorithm uses $\Delta$+1colors, where $\Delta$ is an upper bound on a processor's number of neighbors. [Dolev 2000] Chapter 7 - Local Stabilization, slide 9.

10.b **(2 p) P**lease find below one of the self-stabilizing algorithms for vertex coloring that we learned in class. How long does it takes for the algorithm to convergence. Please give an example for a particularly long convergence period.
In the order of the network diameter [Dolev 2000] Chapter 7 - Local Stabilization, slide 14.

10.c **(4 p)** Does this algorithm guarantee the shortest convergence possible? In case you think that it is, then please give a formal proof for a matching lower bound. In case you think that it is not, please explain how to change the algorithm below so that the convergence time become shorter. (Say which variables needs to be added, rewrite the code and give an example in which the algorithm below takes a long time to converge and the one you write takes a very short time to converge.)

```
Do forever
    GColors := $\emptyset$
    For m:=1 to $\delta$ do
        $lr_m$:=read($r_m$)
        If ID(m)>i then
            GColors := GColors U {$lr_m$.color}
    od
    If $color_i \in$ GColors then
        $color_i$:=choose(\\ GColors)
    Write $r_i$.color := $color_i$
od
```



## Graph Coloring – A Super-Stabilizing Algorithm

```
Do forever
    AColors := $\emptyset$
    GColors := $\emptyset$
    For m:=1 to $\delta$ do
        $lr_m$:=read($r_m$)
        AColors:=AColors U {$lr_m$.color}
        If ID(m)>i then GColors := GColors U $lr_m$.color
    od
    If $color_i = \perp$ or $color_i \in$ GColors then
        $color_i$:=choose(\\ AColors)
    Write $r_i$.color := color
od
Interrupt section
    If $recover_{ij}$ and j > i then
        $Color_i := \perp$
        Write $r_i$.color := $\perp$
```

All of $P_i$ neighbors' colors

Activated after a topology change to identify the critical processor

$recover_{i,j}$ is the interrupt which $P_i$ gets upon a change in the communication between $P_i$ and $P_j$