MA 4207 - Mathematical Logic
Course-Webpage `http://www.comp.nus.edu.sg/~fstephan/mathlogicug.html`
Homework due on Friday of Week 9 (and Tuesday subsequent week).

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Homework 9.1
This homework considers undirected graphs without self-loops. Consider the following two graphs:

```
(a) 0 - 1 - 2           (b) 0  1 - 2
        | /                    | /
        3                      3
```

(a) Prove that in graph (a) nodes 0 and 1 are definable and nodes 2 and 3 are not.
(b) Prove that in graph (b) the node 0 is definable and nodes 1, 2 and 3 are not.
(c) For which n is there a graph of 6 nodes such that exactly n out of these 6 nodes are definable?

Homework 9.2
Let the logical language contain a function symbol f for a function with one input. Show that Λ proves the formulas

$$f(x) = f(y) \to f(y) = f(x),\ f(x) = f(y) \to (f(y) = f(z) \to f(x) = f(z))$$

which is similar to the proves of the corresponding formulas in the lecture without the f.

Homework 9.3
For the following formulas α and terms t, either write what α^z_t is or write that a substitution is not permitted. The formulas are $\exists x\,[\neg(x = z{+}1)]$, $\forall z\,[x = z]$, $f(x{\cdot}z) = f(0)$ and the terms are x, 0, $z + z$. Do not forget to make brackets where needed.

Homework 9.4
For the following formulas α and terms t, either write what α^z_t is or write that a substitution is not permitted. The formulas are $\exists x \forall y\,[x = y \cdot z]$, $\forall x\,\exists y\,[z = x + y]$, $\forall u\,[z \cdot z + 1 \neq u \cdot u + 2]$ and the terms are $x + y$, 0, $v \cdot w$. Do not forget to make brackets where needed.

Homework 9.5
Use the Deduction Theorem to show the following:
If $\Gamma \vdash \alpha \to \beta \to \gamma \to \delta$ then $\Gamma \vdash\ \gamma \to \alpha \to \beta \to \delta$.
Which other interchanges of $\alpha, \beta, \gamma, \delta$ are permitted and which not?

Homework 9.6
Prove the statement from Theorem 9.5 using only tautologies and modus ponens.

Homework 9.7
Let the logical language have a function f and constant c. Prove formally that

$$\{\forall x\, \forall y\, [P(x) \to P(y)]\} \vdash P(c) \to \forall y\, [P(y)]$$

using the axioms of Λ, the Deduction Theorem and the Generalisation Theorem.

Homework 9.8
Let $(A, +, 0)$ be a structure with constant 0 and binary operation $+$. Make a formal proof for

$$\{\forall x\, [x + x = 0]\} \vdash \forall x\, [(x + x) + (x + x) = 0]$$

using axioms from Λ and the Generalisation Theorem.

Homework 9.9
Let $(A, +, 0)$ be a structure with constant 0 and binary operation $+$. Make a formal proof for

$$\{\forall x\, \forall y\, [x + y = y + x]\} \vdash \forall u\, [u + (u + u) = (u + u) + u]$$

using the axioms of Λ and the Generalisation Theorem.

Homework 9.10
For $(A, +, 0)$ as in Homework 9.9, make a formal proof for

$$\{\forall x\, \forall y\, \forall z\, [(x + y) + z = x + (y + z)]\} \vdash \forall u\, [u + (u + u) = (u + u) + u]$$

using the axioms of Λ and the Generalisation Theorem.

Homework 9.11
Is the statement

$$\{\forall x\, \forall y\, [x + y = y + x], \forall x\, \forall y\, \forall z\, [(x + y) + z = x + (y + z)]\} \models \forall x\, \forall y\, \exists z\, [x + z = y]$$

true? If the statement is true then make a formal proof else provide a model satisfying the left but not the right side of $\models$.