

## syn.1 Free Variables and Sentences

fol:syn:fvs:  
sec

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defn:free-occ

**Definition syn.1** (Free occurrences of a variable). The *free* occurrences of a variable in a formula are defined inductively as follows:

1.  $\varphi$  is atomic: all variable occurrences in  $\varphi$  are free.
2.  $\varphi \equiv \neg\psi$ : the free variable occurrences of  $\varphi$  are exactly those of  $\psi$ .
3.  $\varphi \equiv (\psi * \chi)$ : the free variable occurrences of  $\varphi$  are those in  $\psi$  together with those in  $\chi$ .
4.  $\varphi \equiv \forall x \psi$ : the free variable occurrences in  $\varphi$  are all of those in  $\psi$  except for occurrences of  $x$ .
5.  $\varphi \equiv \exists x \psi$ : the free variable occurrences in  $\varphi$  are all of those in  $\psi$  except for occurrences of  $x$ .

**Definition syn.2** (Bound Variables). An occurrence of a variable in a formula  $\varphi$  is *bound* if it is not free.

**Problem syn.1.** Give an inductive definition of the bound variable occurrences along the lines of Definition syn.1.

**Definition syn.3** (Scope). If  $\forall x \psi$  is an occurrence of a subformula in a formula  $\varphi$ , then the corresponding occurrence of  $\psi$  in  $\varphi$  is called the *scope* of the corresponding occurrence of  $\forall x$ . Similarly for  $\exists x$ .

If  $\psi$  is the scope of a quantifier occurrence  $\forall x$  or  $\exists x$  in  $\varphi$ , then all occurrences of  $x$  which are free in  $\psi$  are said to be *bound by* the mentioned quantifier occurrence.

**Example syn.4.** Consider the following formula:

$$\exists v_0 \underbrace{A_0^2(v_0, v_1)}_{\psi}$$

$\psi$  represents the scope of  $\exists v_0$ . The quantifier binds the occurrence of  $v_0$  in  $\psi$ , but does not bind the occurrence of  $v_1$ . So  $v_1$  is a free variable in this case.

We can now see how this might work in a more complicated formula  $\varphi$ :

$$\forall v_0 \underbrace{(A_0^1(v_0) \rightarrow A_0^2(v_0, v_1))}_{\psi} \rightarrow \exists v_1 \underbrace{(A_1^2(v_0, v_1) \vee \forall v_0 \overbrace{\neg A_1^1(v_0)}^{\theta})}_{\chi}$$

$\psi$  is the scope of the first  $\forall v_0$ ,  $\chi$  is the scope of  $\exists v_1$ , and  $\theta$  is the scope of the second  $\forall v_0$ . The first  $\forall v_0$  binds the occurrences of  $v_0$  in  $\psi$ ,  $\exists v_1$  the occurrence of  $v_1$  in  $\chi$ , and the second  $\forall v_0$  binds the occurrence of  $v_0$  in  $\theta$ . The first occurrence of  $v_1$  and the fourth occurrence of  $v_0$  are free in  $\varphi$ . The last occurrence of  $v_0$  is free in  $\theta$ , but bound in  $\chi$  and  $\varphi$ .

**Definition syn.5** (Sentence). A formula  $\varphi$  is a *sentence* iff it contains no free occurrences of variables.

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**Bibliography**