General recursion, $\text{fix } x : \tau \text{ is } e$, is only sensible in a by-name dynamics for PCF, because it steps to $[\text{fix } x : \tau \text{ is } e/x]e$, which substitutes a non-value for the variable $x$ in the expression $e$. In a by-value dynamics general recursion is, for this reason, not sensible and must be replaced by type-specific forms of self-reference, such as the self-referential function form $\text{fun} (\tau_1 ; \tau_2 ) ( f . x . e )$, which is postulated to be a value of type $\tau_1 \rightarrow \tau_2$. Such a function is a value that is unrolled on application, substituting the recursive function value itself for the recursive variable, $f$, in the body of the function.

In FPC an alternative account of self-reference is provided by the recursive type $\tau \text{ self}$, the type of self-referential values $\text{self } x \text{ is } e$. Within $e$ the self-reference, $x$, must be unrolled, writing $\text{unroll}(x)$, to unroll the recursion and access the underlying expression $e$. More precisely,

$$\text{unroll}(\text{self } x \text{ is } e) \mapsto [\text{self } x \text{ is } e/x]e,$$

which makes sense in either a by-name or a by-value dynamics.

Using self types the recursive factorial function has type $(\text{nat} \rightarrow \text{nat}) \text{ self}$, which reveals in its type that it is self-referential. To call such a function, either externally or internally within its definition, it is necessary to first unroll the self-reference and apply it to an argument, which may be either a value or a computation, depending on the dynamics. In any case the self-referential variable is only ever replaced by a value.

Curiously, in FPC it is possible to define fix from self, obtaining the expected dynamics, even under a by-value interpretation! The idea is that the “self” type $\tau \text{ self}$ forces the recursively-defined computation to unroll the recursion before using it. Specifically, definee $\hat{e}$ to be $[\text{unroll}(x)/x]e$, and then define $\text{fix } x : \tau \text{ is } e$ to be the expression $\text{unroll}(\text{self } x \text{ is } \hat{e})$. Then observe the following transition:

$$\text{fix } x : \tau \text{ is } e = \text{unroll}(\text{self } x \text{ is } \hat{e})$$

$$\mapsto [\text{self } x \text{ is } \hat{e}/x]\hat{e}$$

$$= [\text{self } x \text{ is } \hat{e}/x][\text{unroll}(x)/x]e$$

$$= [\text{unroll}(\text{self } x \text{ is } \hat{e})/x]e$$

$$= [\text{fix } x : \tau \text{ is } e/x]e.$$

The penultimate line summarizes the result of the iterated substitution; it does not arise in the dynamics itself as a substitution of a non-value for a variable, which would be disallowed in the by-value case.
References