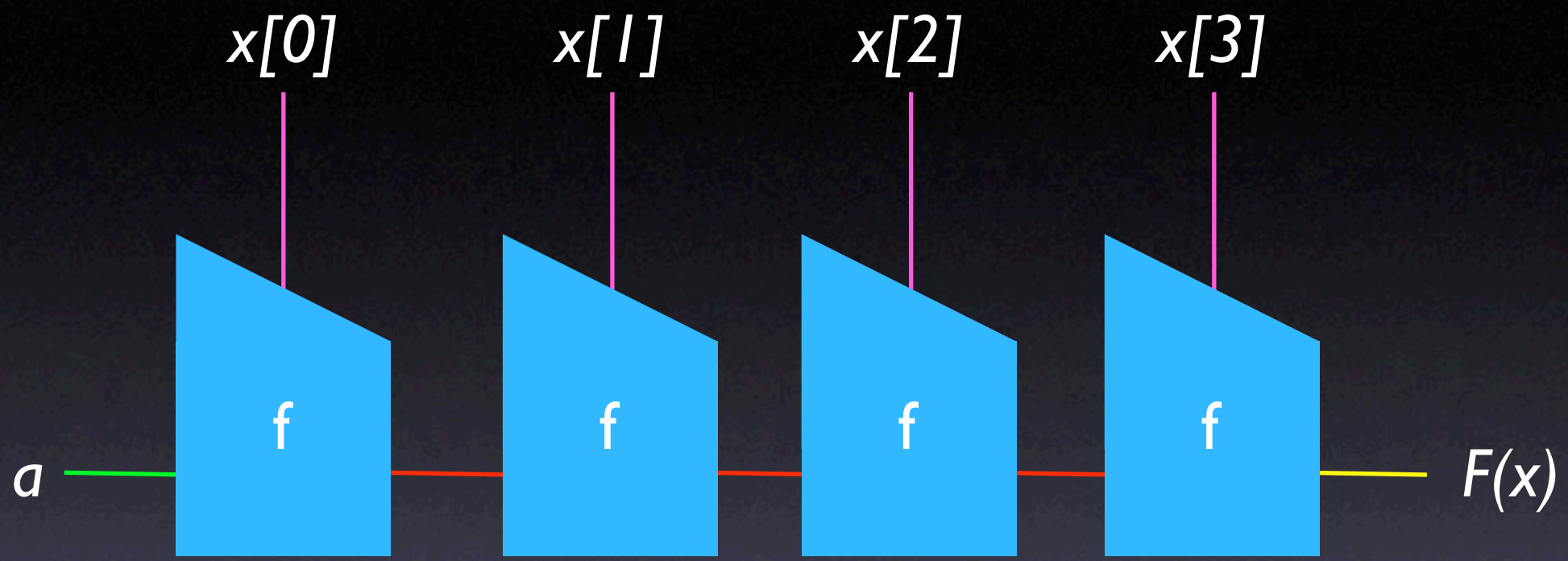
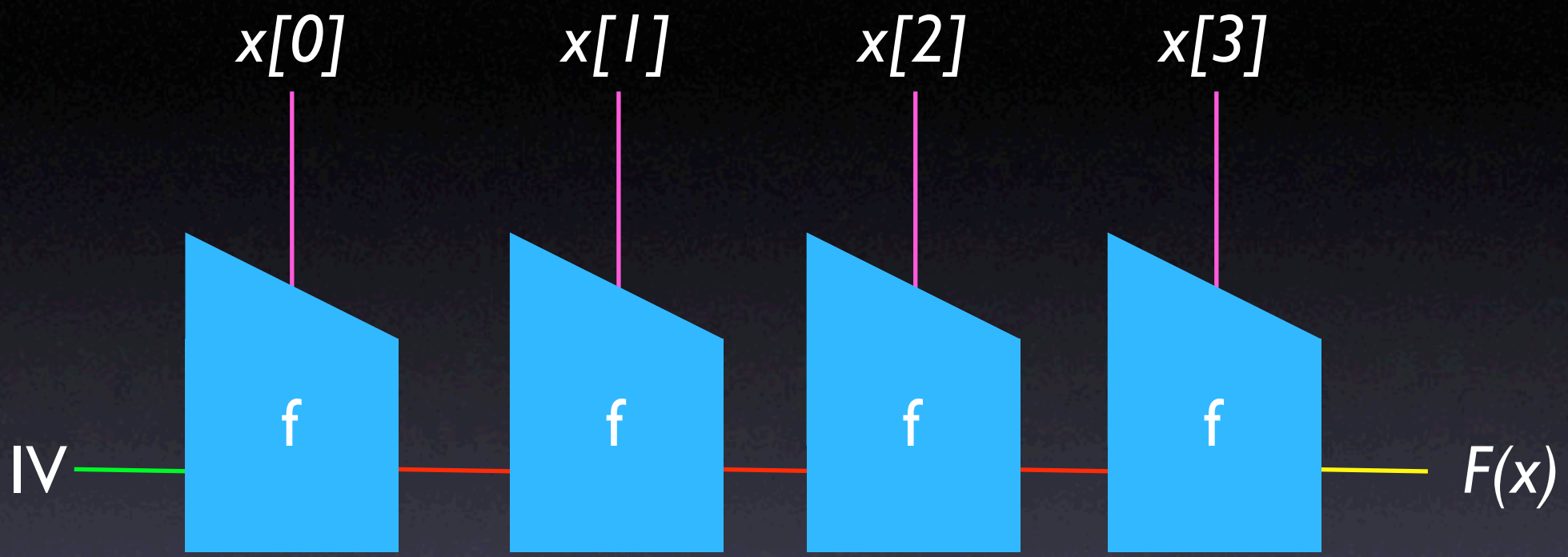
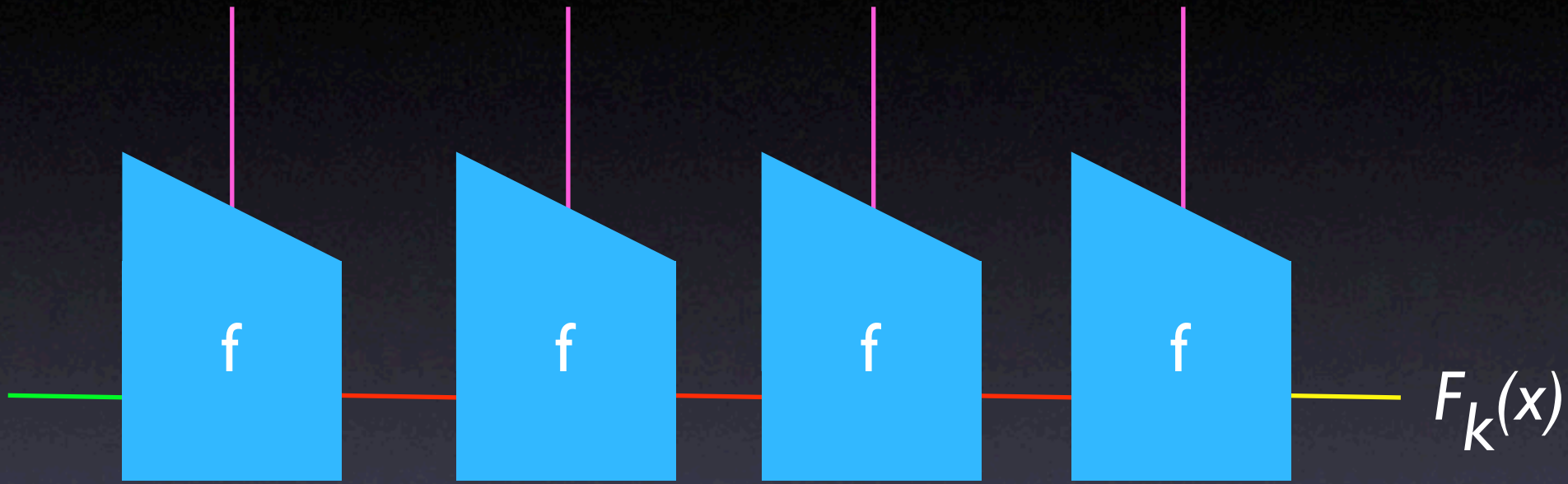
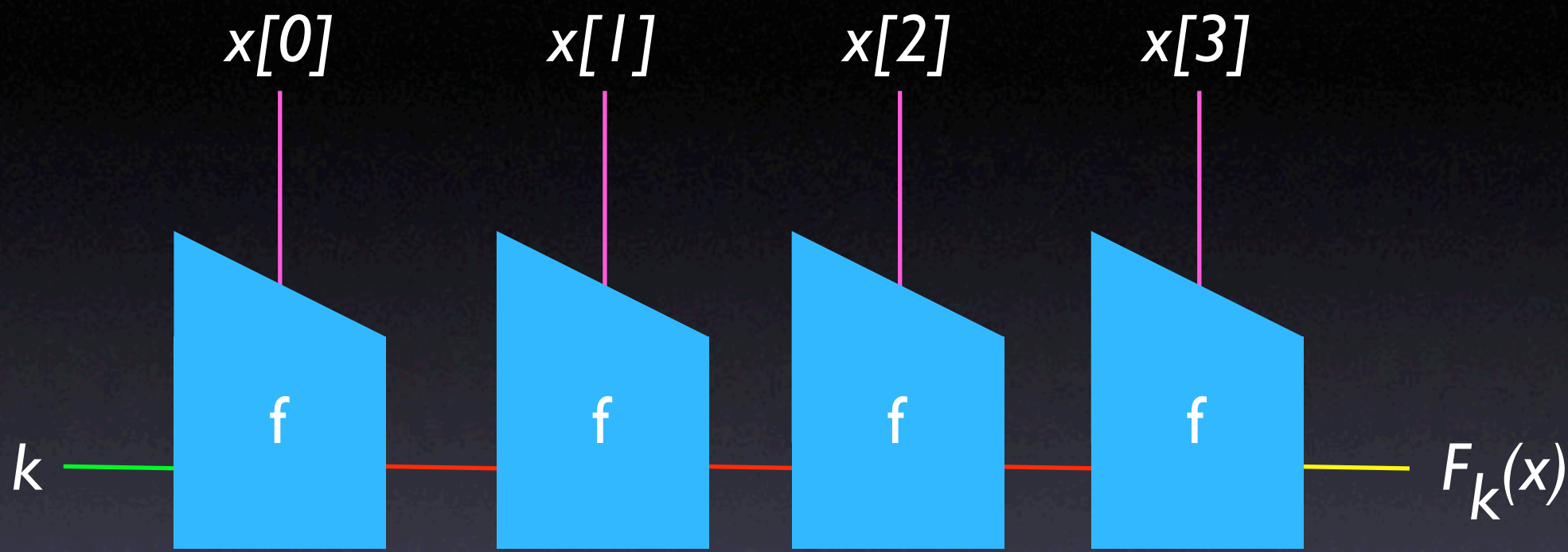
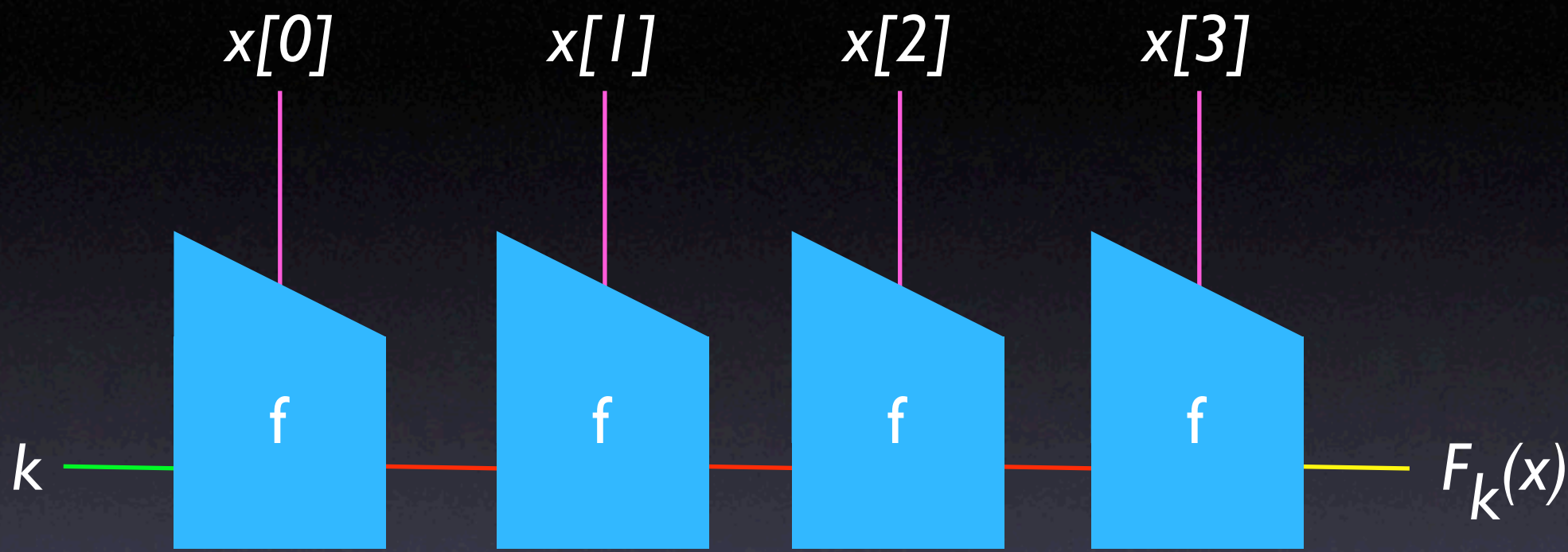

x[0]
x[1]
x[2]
x[3]
f
f
f
f
a
F(x)

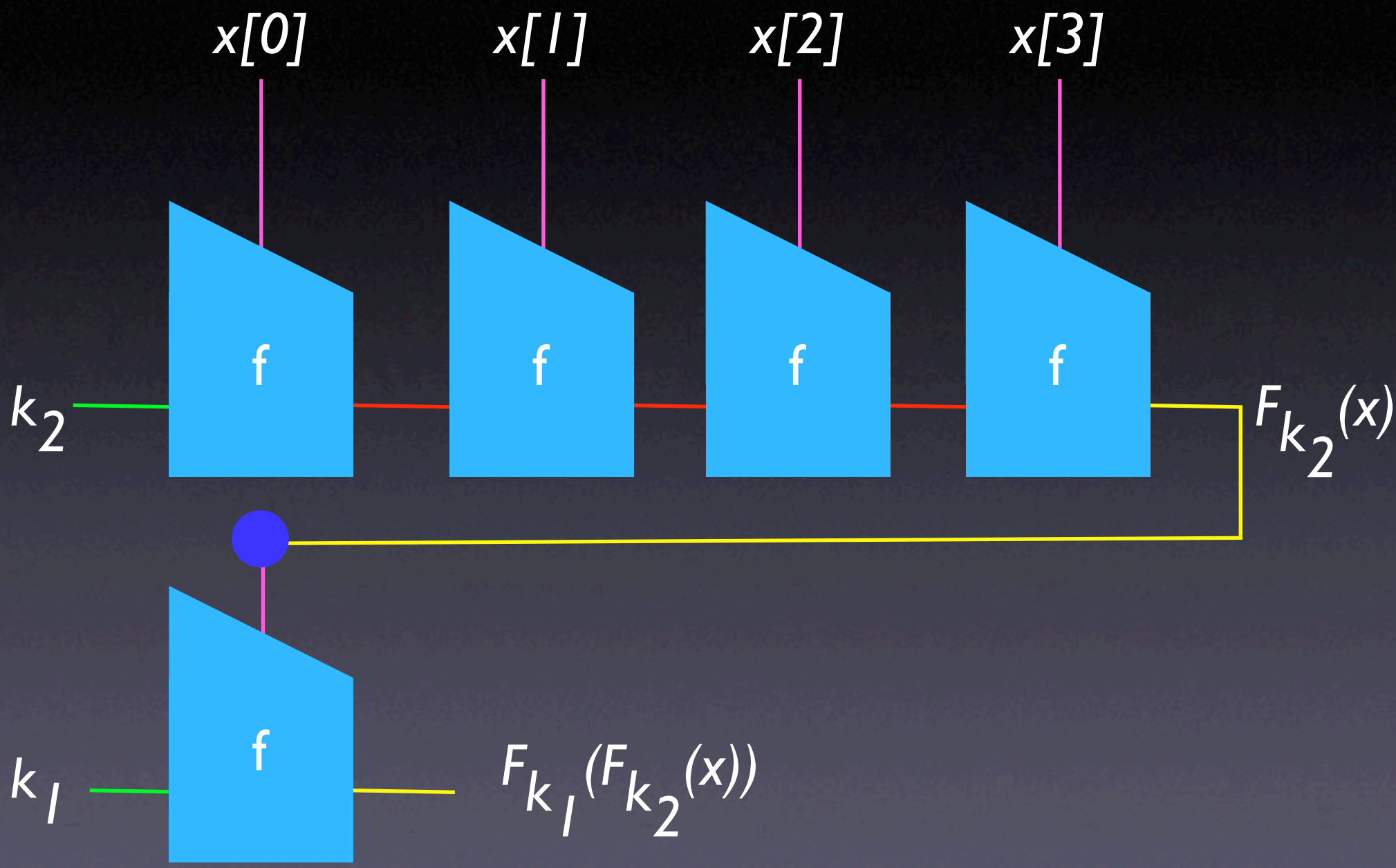

x[0]
x[1]
x[2]
x[3]
IV
f
f
f
f
F(x)


f
f
f
f
$F_k(x)$

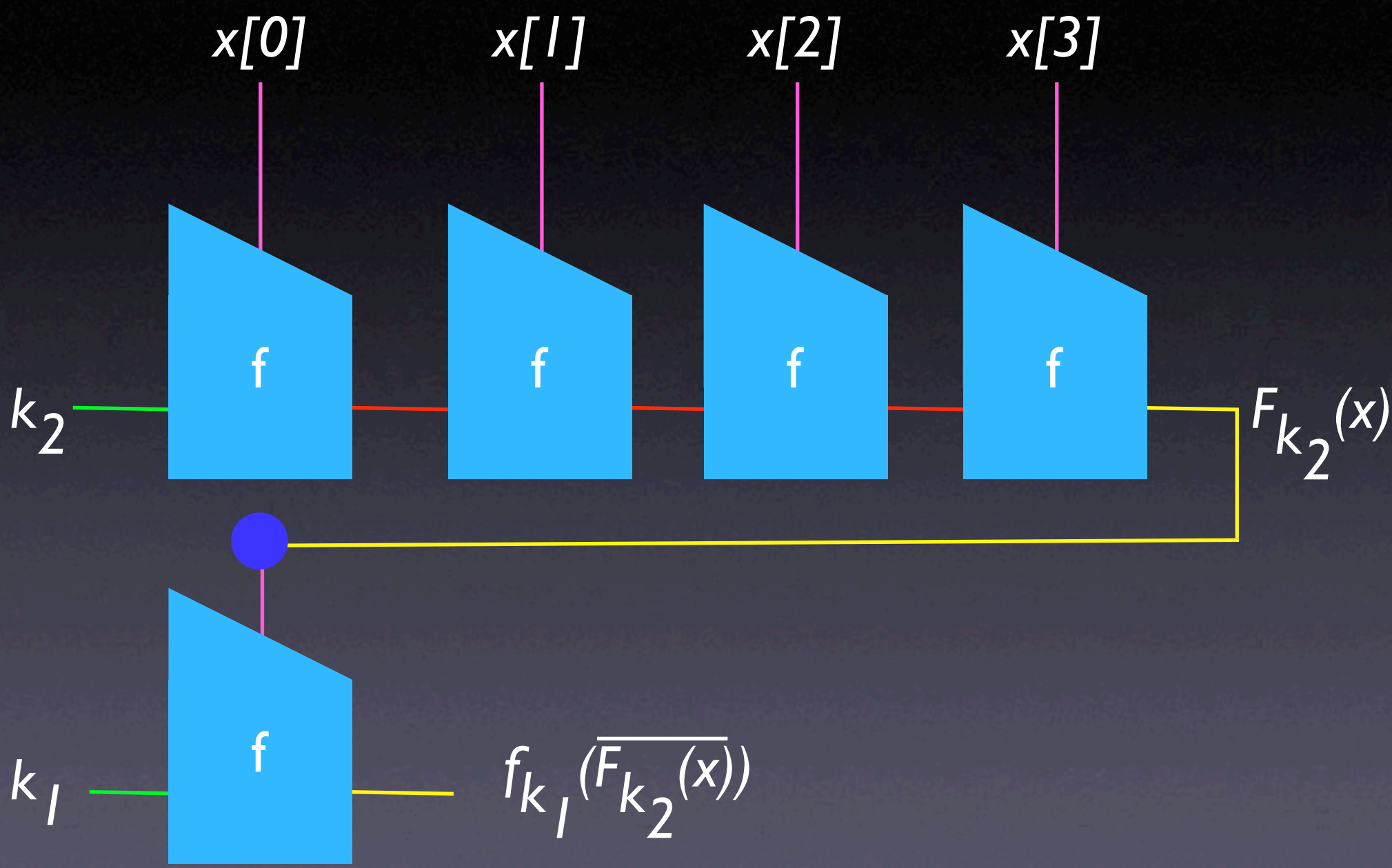

x[0]
x[1]
x[2]
x[3]
f
f
f
f
k
$F_k(x)$


x[0]
x[1]
x[2]
x[3]
f
f
f
f
k
$F_k(x)$

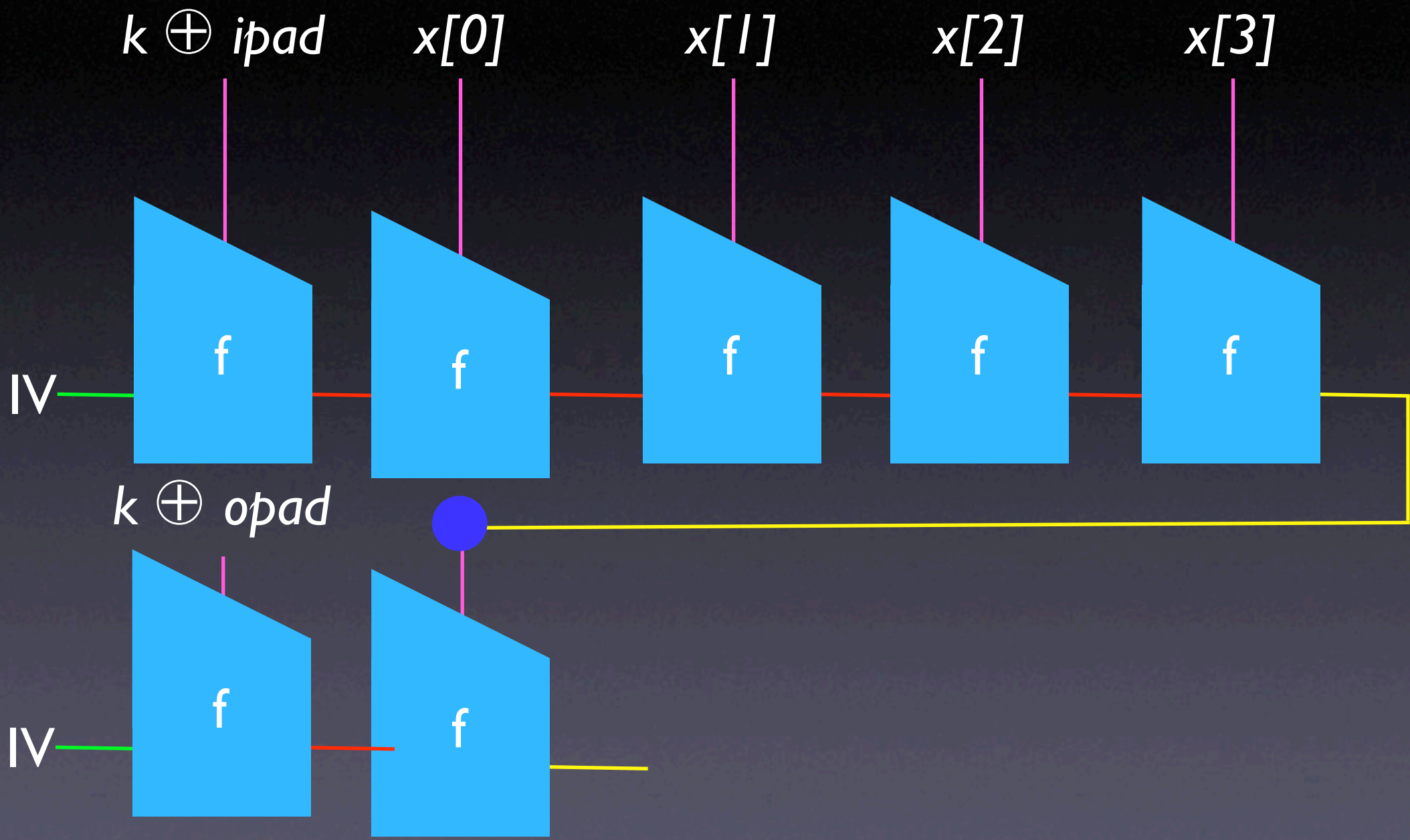
$$\mathrm{NMAC}_{k_1,k_2}(x) = F_{k_1}(F_{k_2}(x))$$



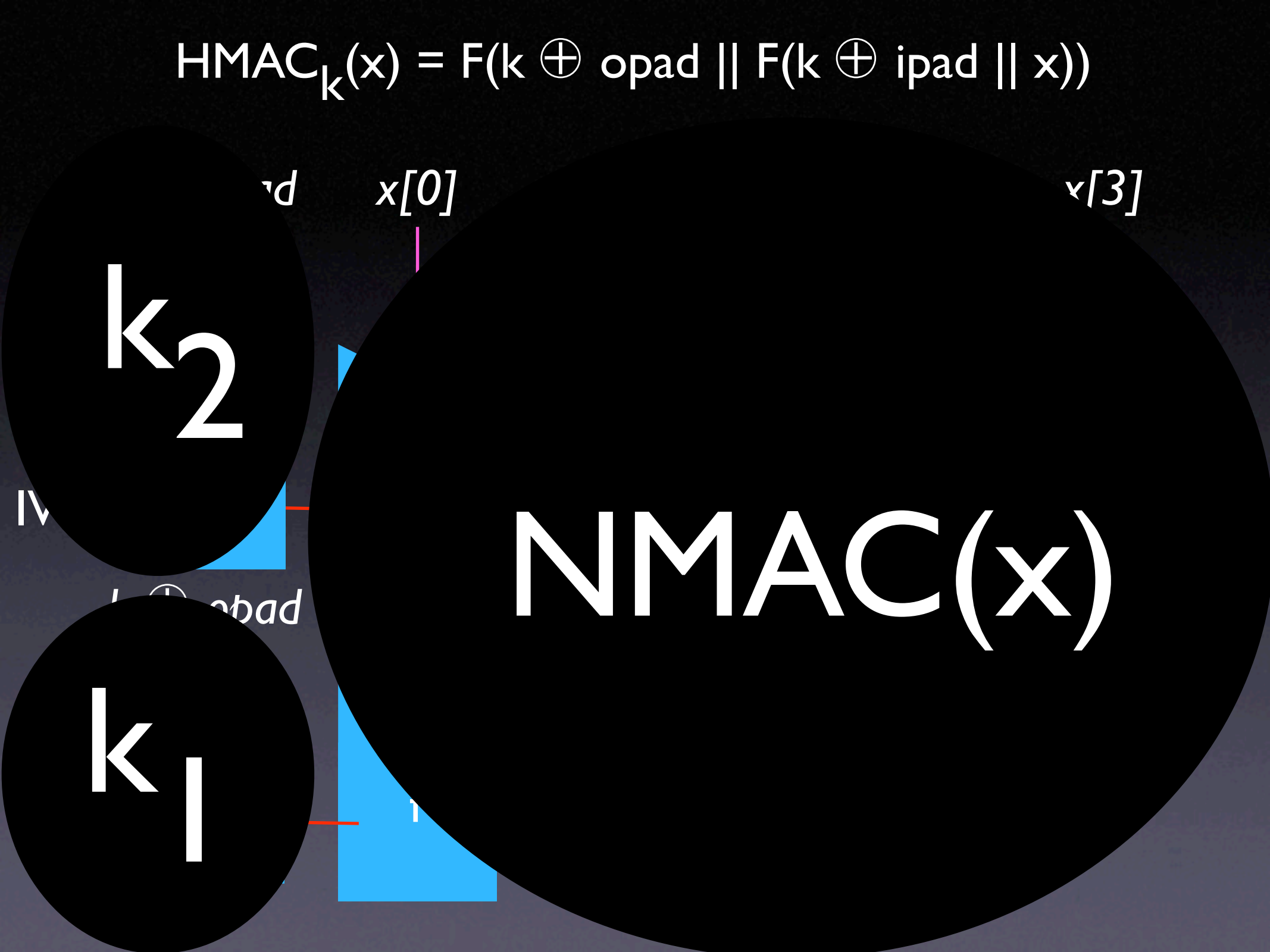
$$NMAC_{k_1,k_2}(x) = F_{k_1}(F_{k_2}(x))$$



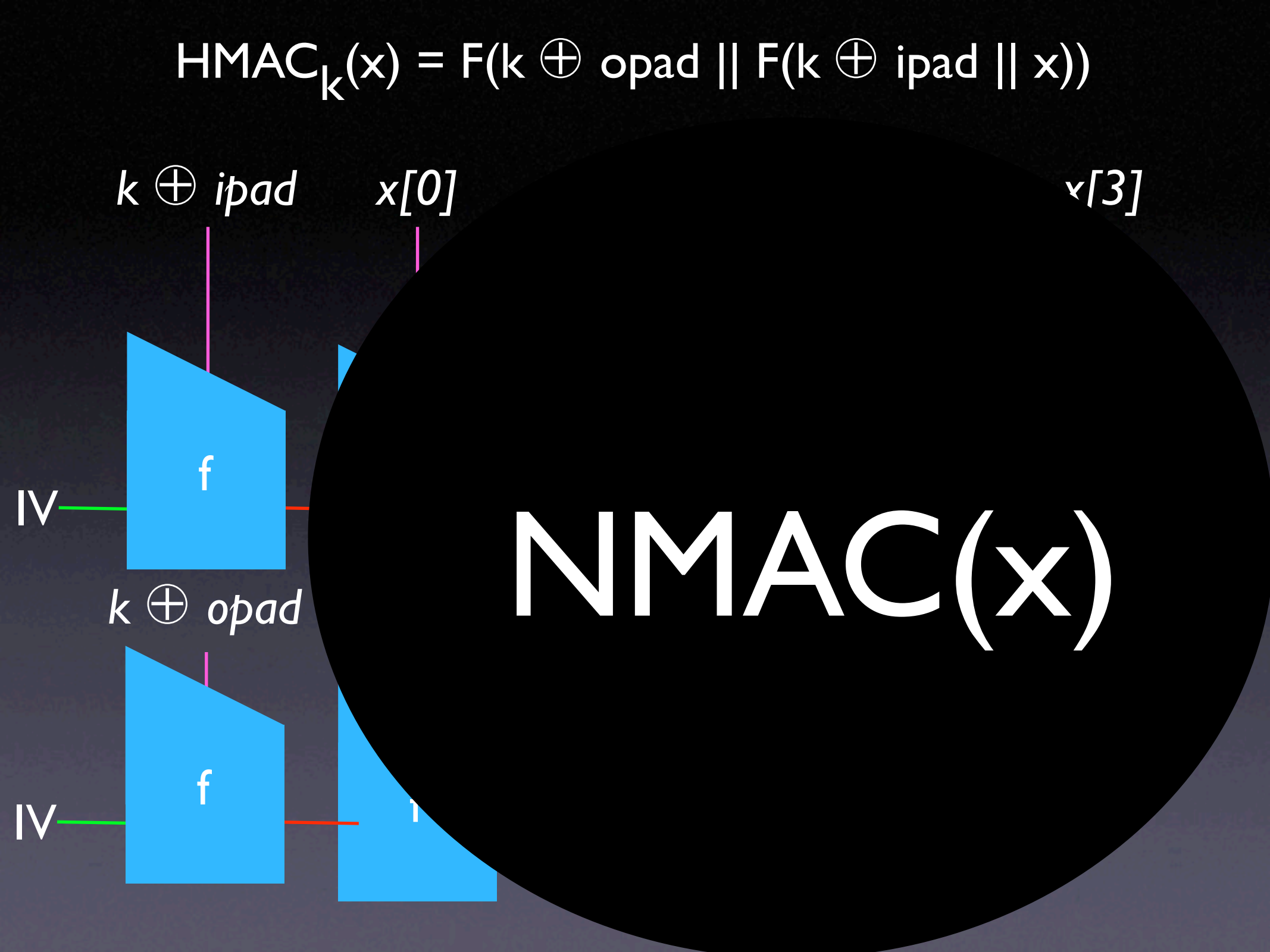
$$HMAC_k(x) = F(k \oplus opad \,||\, F(k \oplus ipad \,||\, x))$$



$$HMAC_k(x) = F(k \oplus opad \,||\, F(k \oplus ipad \,||\, x))$$



$$HMAC_k(x) = F(k \oplus opad \,||\, F(k \oplus ipad \,||\, x))$$



What Happens If the Hash Function Breaks?

- The security of the NMAC is related to the security of the underlying hash
- If someone can break NMAC, we can break the hash
- If someone comes up with an attack on a hash function, does that mean that NMAC with that hash is broken?

Short Answer:
It Depends

Concrete Example

- Lots of systems use the hash function MD5 with HMAC - often notated HMAC-MD5
- Last month, it was shown that collisions can be found in MD5 (in about an hour)
- Thus, MD5 is not collision resistant
- Does that mean HMAC-MD5 isn't a secure MAC?

If the keyed compression function *f* is a (...)-secure MAC and the keyed iterated hash *F* is (...)-weakly collision resistant, then NMAC is a (..)-secure MAC

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If the conditions of the theorem aren't satisfied, it doesn't mean NMAC is broken - just that we don't have a proof that it's secure

Should we continue to use HMAC-MD5?