QWeSST

Type-Safe Web Programming

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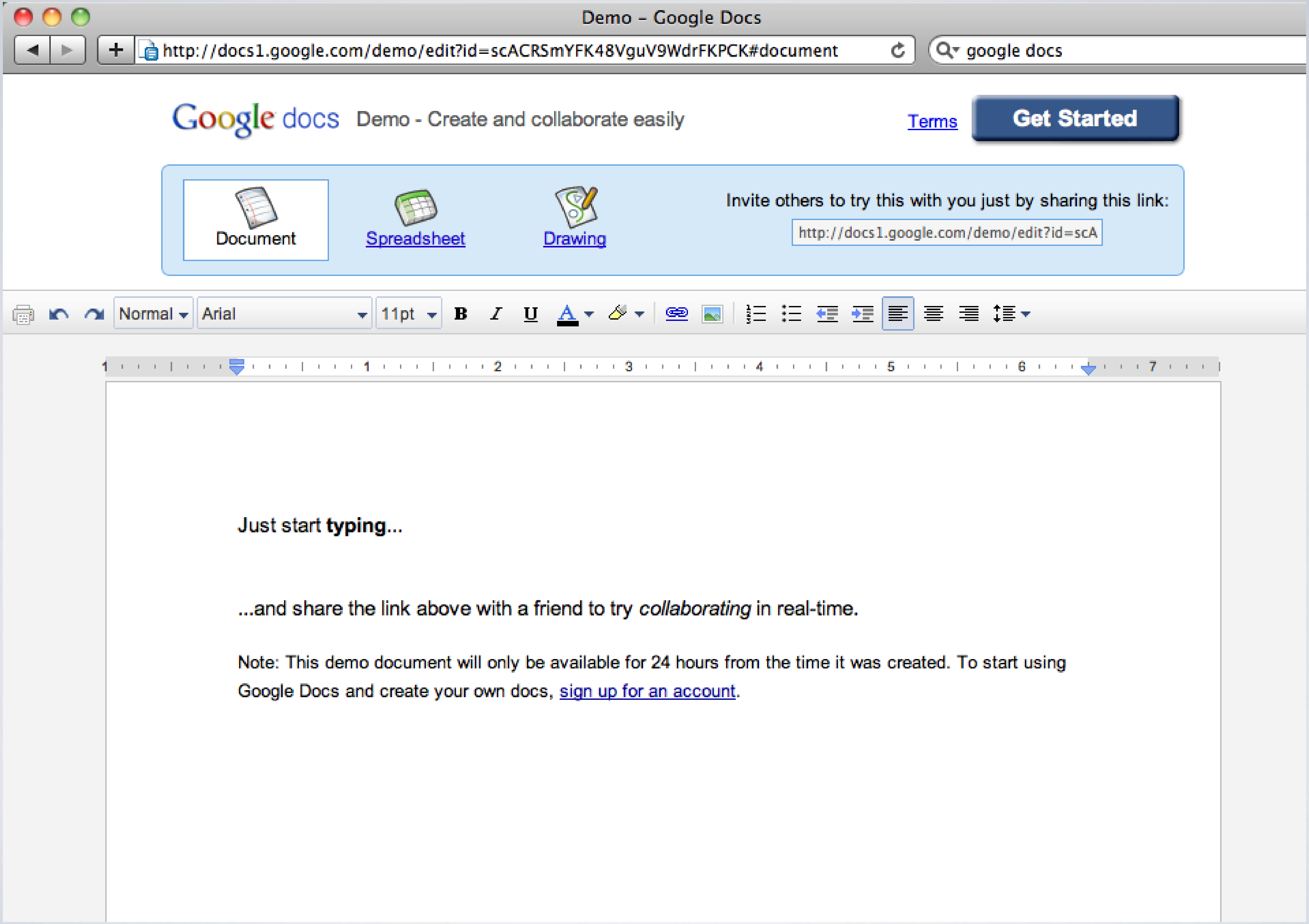
Demo – Google Docs
http://docs1.google.com/demo/edit?id=scACRSmYFK48VguV9WdrFKPCK#document
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- **Project Goal**
  - ➡ Study the foundations of web programming
- **Outcomes**
  - ➡ QWeSST: a type-safe programming language for the web
  - ➡ Faithful semantics description for parallel languages
  - ➡ QWeSST$^{\varphi}$: managing distributed flow of data on the web

Web Programming

Anatomy of a Web Application

JavaScript

HTML
PHP
Java
ASP/.Net
Ruby
Python
Server JS

- Mobile code
- Remote execution
- State
- Security

Limitation of current web technologies

- ➡ Use of **heterogeneous languages** (not originally designed with distributed computing in mind)
- ➡ Require **heavy testing**
- ◉ Setting up the communication machinery is expensive and error prone

Partial solution – Better libraries

- Simplifying the communication machinery

➡ Abstract libraries (such as JQuery and Prototype)

- But we still have to care about requests and callbacks

```
<script type="text/javascript" src="prototype.js"></script>
<script language="javascript" type="text/javascript">
function sendRequest(arg)
{
    // Do something with the Ajax response
    function doSomething(result)
    {
        $('resultDiv').update(result.responseText);
    }

    // send the Ajax request
    new Ajax.Request('helloService.php',
                     { method: 'post',
                       parameters: arg,
                       onComplete: doSomething});
}
</script>
```

Partial solution – **One** language

Write an entire webapp in the same language

➡ Google Web Toolkit, LINKS, HOP

- Programmer designates code as client or server
- Compiled to JavaScript or Java

➡ Flash, Silverlight

- Interpreted in the browser

Complexity is rising

- Webapps are getting more and more **sophisticated** and **distributed**

- Current technologies are unlikely to be able to support this **growing complexity**

QWeSST

A Type-Safe Programming Language for the Web

Looking for foundations of web programming

- A language to carry out local computations

✓ A λ-calculus

- Constructs to **publish** code and **call** it through a URL

✓ Remote procedure mechanism

- Constructs to **suspend** and **resume** a computation

✓ Mobile code

in a well-typed fashion

Remote Procedures

Types $\tau \ ::= \ldots \mid \tau \hookrightarrow \tau'$

Expressions $e \ ::= \ldots \mid \mathrm{w}/u \mid \text{publish } x{:}\tau.\ e \mid \text{call } e_1 \text{ with } e_2$

- Browser to web server

  - **Web pages**
  - **Ajax**

```
function factorial(n){
    new Ajax.Request(www.example.com/factorial.php,{
            method: 'get',
            parameters: "arg="+n,
            onSuccess: function(response){alert(response.responseText)}});}
```

- Web server to web server
  - **XML/RPC** (web service)

```
<soapenv:Envelope xmlns:soapenv="http://schemas.xmlsoap.org/soap/en
   <soapenv:Header/>
   <soapenv:Body>
      <getFactorial>
         <param>6</param>
      </getFactorial>
   </soapenv:Body>
</soapenv:Envelope>
```

publish / call

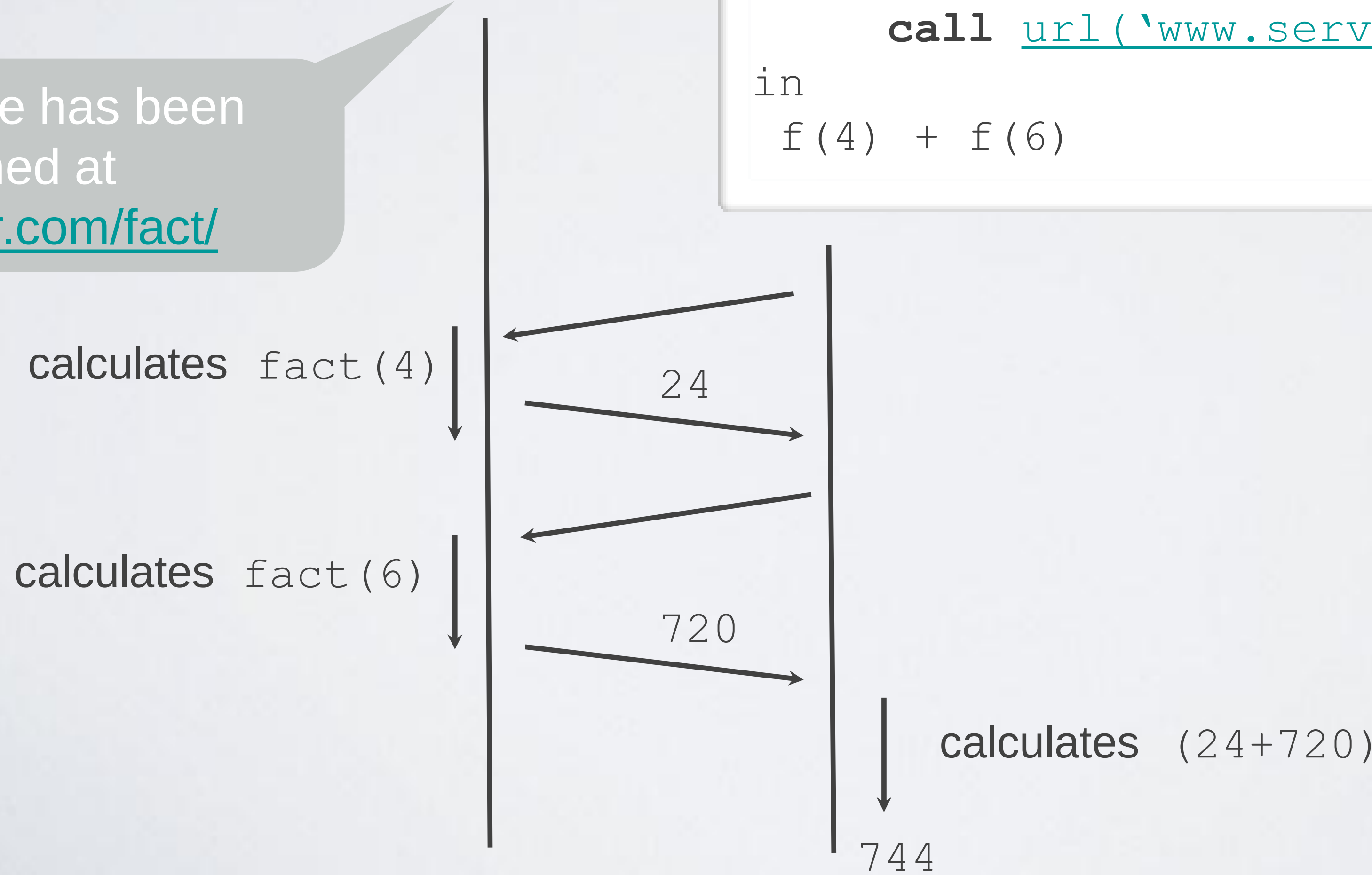
Server

```
let
fun fact(n) => if = 0 then 1
                else n * fact(n-1)
in
publish x => fact(x)
```

A new service has been published at www.server.com/fact/

```
let
 fun f(x) =>
     call url('www.server.com/fact/') with x
in
 f(4) + f(6)
```

Client



Mobile Code

Types τ ::= ... | susp[τ]

Expressions e ::= ... | hold e | resume e

- Web server to browser
  - **Javascript** code

```
<script type="text/javascript" src="includes/prototype.js"></script>

<script language="javascript" type="text/javascript">

function logout()
{
    new Ajax.Request('clearSession', {onComplete: function (obj){locat
```

- Web server to web server
  - Not done in practice

hold / resume

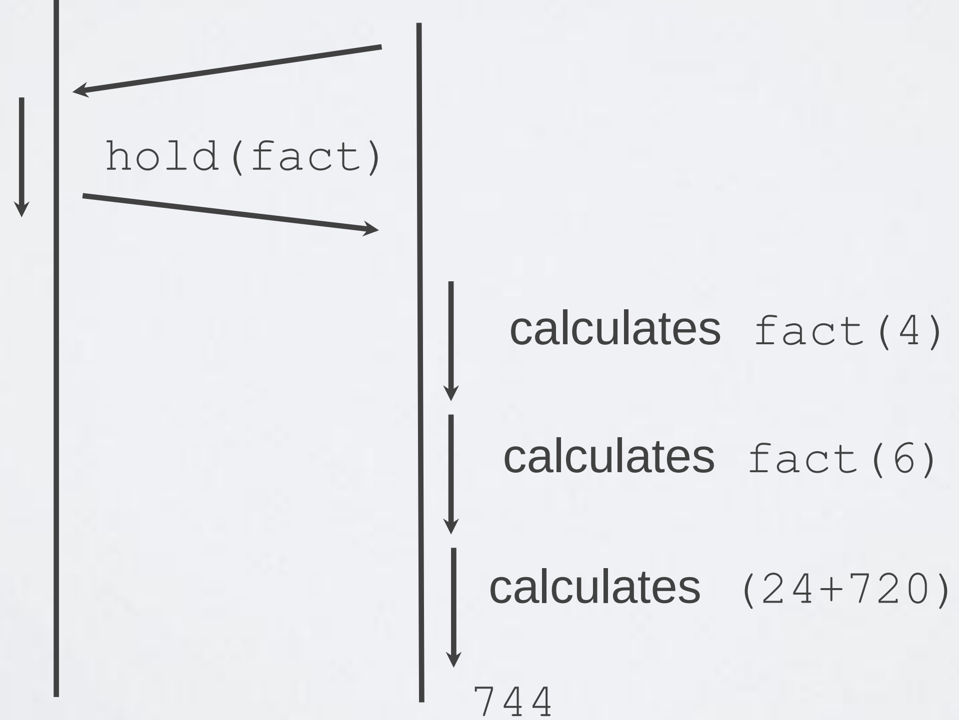
Server

```
let
fun fact(n) => if n= 0 then 1
                 else n * fact(n-1)
in
   publish x => hold(fact)
```

A new service has been published at www.server.com/fact/

```
let
 f = resume (call url('www.server.com/fact/') with ())
in
 f(4) + f(6)
```

Client



Web pages vs. Web services

✓ Web pages and web services are treated uniformly

➡ It is all about calling a URL (with some parameters) and getting a result back

➡ The difference is how the result is used


```
function factorial(n){
    new Ajax.Request(www.example.com/factorial.php,{
            method: 'get',
            parameters: "arg="+n,
            onSuccess: function(response){alert(response.responseText)}});}
```

QWeSST - A language for web programming

- A simple abstraction of the way we program the web

✓ Easier to reason about complex web programs

- Currently a **pure** language (no effects)
- **Static** and **localized** type semantics
  - **Localized** type checking

✓ **Globally type safe** language

More examples

- Custom Web Service
- Web API
- Custom Web API
- Web service auto-installer

➡ Check the Qwesst website:
http://tsans-mac.qatar.win.cmu.edu/

An API

Server

```
let
search = url('www.server.com/search/')
script = hold (fn x => call search with x)
in
publish x => script
```

Client

```
let
api = url('www.server.com/api/')
s = resume (call api with ())
in
s('myRequest')
```

A new service has been published at www.server.com/api/

A Web Service Auto-installer

Server

```
let
search = url('www.server.com/search/')
f = (fn x => call search with x)
script = hold (publish x => f(x))
in
publish x => script
```

Client

```
let
installer = url('www.server.com/inst/')
in
resume (call installer with ())
```

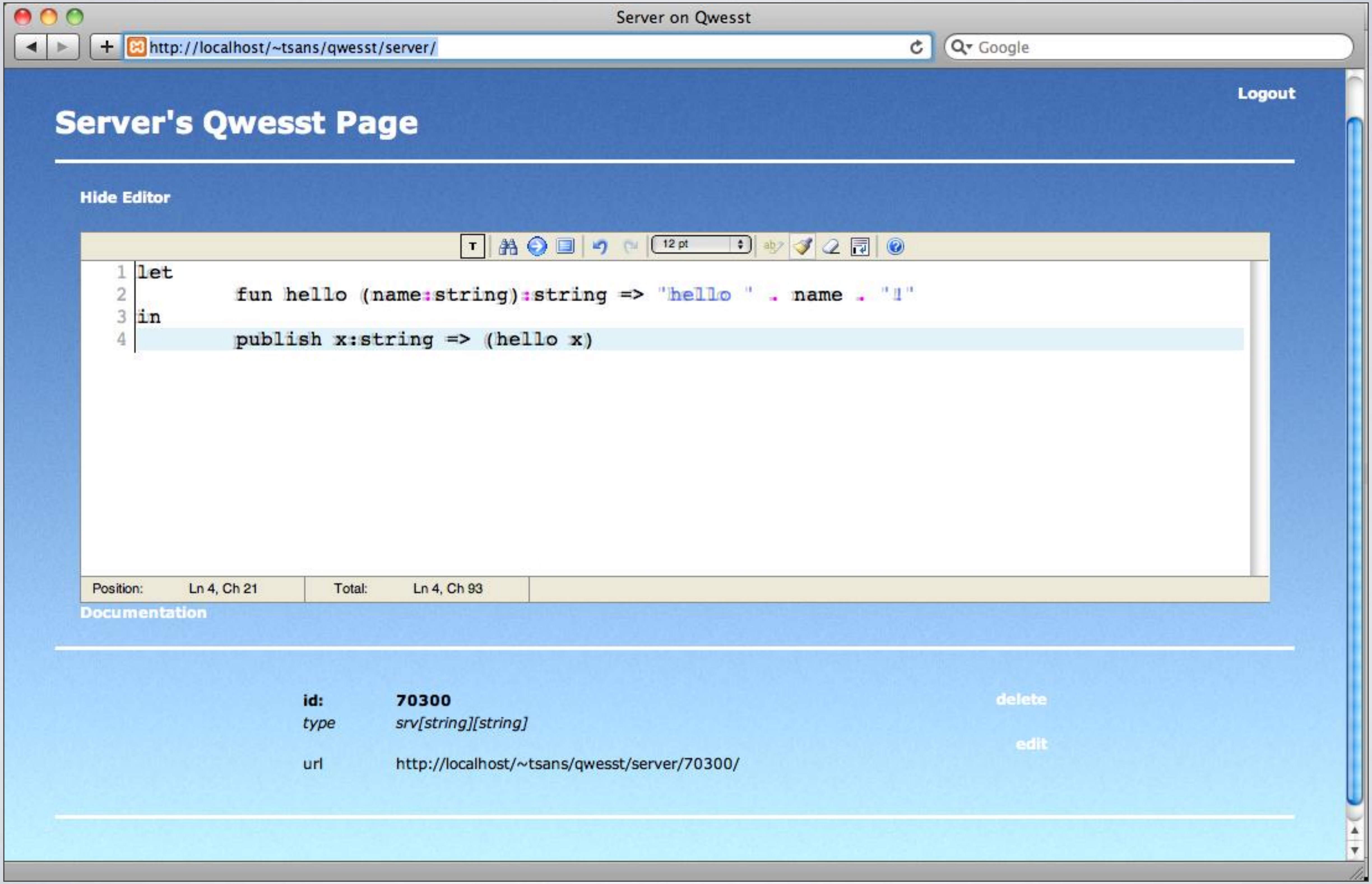
Customer

```
let
f = url('www.client.com/search/')
in
call f with 'myQuery'
```

A new service has been published at www.server.com/inst/

A new service has been published at www.client.com/search/

Demo



Server on Qwesst
http://localhost/~tsans/qwesst/server/
Google
Logout
Server's Qwesst Page
Hide Editor
12 pt
1 let
2 fun hello (name:string):string => "hello " . name . "!"
3 in
4 publish x:string => (hello x)
Position: Ln 4, Ch 21
Total: Ln 4, Ch 93
Documentation
id: 70300
type srv[string][string]
url http://localhost/~tsans/qwesst/server/70300/
delete
edit

QWeSST

Formal Semantics

Typing

Internet Expression Type

$\Sigma; \Gamma \vdash_{w} e : \tau$ (e has type τ at w in Σ and Γ)

Local context Location

- Inspired to ***ML5's type system for localized computation*** by Tom Murphy VII, Karl Crary and Robert Harper

Typing Semantics

Remote Procedure Call

$$\frac{\tau \hookrightarrow \tau' \text{ mobile}}{\Sigma, \mathrm{w}'/u{:}\ \tau \hookrightarrow \tau';\ \Gamma \mid\!-_{\mathrm{w}} \mathrm{w}'/u : \tau \hookrightarrow \tau'}$$

$$\frac{\tau \hookrightarrow \tau' \text{ mobile} \qquad \Sigma;\ \Gamma, x : \tau \mid\!-_{\mathrm{w}} e : \tau'}{\Sigma;\ \Gamma \mid\!-_{\mathrm{w}} \text{publish}\ \ x{:}\tau.\ e : \tau \hookrightarrow \tau'}$$

$$\frac{\Sigma;\ \Gamma \mid\!-_{\mathrm{w}} e_1 : \tau \hookrightarrow \tau' \qquad \Sigma;\ \Gamma \mid\!-_{\mathrm{w}} e_2 : \tau}{\Sigma;\ \Gamma \mid\!-_{\mathrm{w}} \text{call}\ e_1\ \text{with}\ e_2 : \tau'}$$

Mobile Code

$$\frac{\Sigma;\ \Gamma \mid\!-_{\mathrm{w}} e : \tau}{\Sigma;\ \Gamma \mid\!-_{\mathrm{w}} \text{hold}\ e : \text{susp}[\tau]}$$

$$\frac{\Sigma;\ \Gamma \mid\!-_{\mathrm{w}} e : \text{susp}[\tau]}{\Sigma;\ \Gamma \mid\!-_{\mathrm{w}} \text{resume}\ e : \tau}$$

Evaluation

Internet

Expression

$\Delta; e \Rightarrow_w \Delta'; e'$

Location

(Δ; e steps to Δ'; e')

Evaluation Semantics

Remote Procedure Call

$$\frac{}{\Delta;\ \text{publish}\ \ x{:}\tau.\ e \ \Rightarrow_{\mathrm{w}}\ (\Delta,\ \mathrm{w}/u = x{:}\tau.\ e);\ \mathrm{w}/u}$$

$$\frac{v_2\ \text{val}}{\underbrace{(\Delta',\ \mathrm{w'}/u = x{:}\tau.\ e)}_{\Delta};\ \text{call}\ \mathrm{w'}/u\ \text{with}\ v_2 \ \Rightarrow_{\mathrm{w}}\ \Delta;\ \text{expect}\ [v_2\,/x]\ e\ \text{from}\ \mathrm{w'}}$$

$$\frac{\Delta;\ e \ \Rightarrow_{\mathrm{w'}}\ \Delta';\ e'}{\Delta;\ \text{expect}\ e\ \text{from}\ \mathrm{w'} \ \Rightarrow_{\mathrm{w}}\ \Delta';\ \text{expect}\ e'\ \text{from}\ \mathrm{w'}}$$

$$\frac{v\ \text{val}}{\Delta;\ \text{expect}\ v\ \text{from}\ \mathrm{w'} \ \Rightarrow_{\mathrm{w}}\ \Delta;\ v}$$

Mobile Code

$$\frac{\Delta;\ e \ \Rightarrow_{\mathrm{w}}\ \Delta';\ e'}{\Delta;\ \text{resume}\ e \ \Rightarrow_{\mathrm{w}}\ \Delta';\ \text{resume}\ e'}$$

$$\frac{}{\Delta;\ \text{resume}\ (\text{hold}\ e) \ \Rightarrow_{\mathrm{w}}\ \Delta;\ e}$$

Meta-theory

✓ QWeSST is **type safe** (proof verified using Twelf)

➡ Type preservation

If $\Sigma; . \vdash_w e : \tau$ and $\Sigma \vdash \Delta$ and $\Delta; e \Rightarrow_w \Delta'; e'$,
then $\Sigma'; . \vdash_w e' : \tau$ and $\Sigma' \vdash \Delta'$

➡ Progress

If $\Sigma; . \vdash_w e : \tau$ and $\Sigma \vdash \Delta$, then

- either e val
- or $\Delta; e \Rightarrow_w \Delta'; e'$

Parallel Semantics

A Semantic Mismatch

$$\Delta; e \Rightarrow_{\mathrm{w}} \Delta'; e'$$

- One expression at a time is evaluating
  - Single-threaded
- This is not the way the web works
  - Millions of executions occurring simultaneously
  - Possibly on the same node

Serialized semantics

- Parallelism reduced to non-deterministic interleaving

- Macro-step as series of micro-steps

$$\frac{}{\Delta;\ .\ \Rightarrow\ \Delta;\ .} \qquad \frac{\Delta;\ e\ {}_{?}\!\!\Rightarrow_{\mathrm{w}}\ (\Delta,\Delta');\ e' \qquad \Delta;\ E\ \Rightarrow\ (\Delta,\Delta'');\ E'}{\Delta;\ (e\ @\ \mathrm{w},\ E)\ \Rightarrow\ (\Delta,\Delta',\Delta'');\ (e'\ @\ \mathrm{w},\ E')}$$

  - Serialized typing semantics

$$\frac{}{\Sigma\ |\text{-}\ .\ :\ .} \qquad \frac{\Sigma;\ .\ |\text{-}_{\mathrm{w}}\ e : \tau \qquad \Sigma\ |\text{-}\ E : \mathrm{T}}{\Sigma\ |\text{-}\ (e\ @\ \mathrm{w},\ E) : \tau\ ,\ \mathrm{T}}$$

  - Serialized safety proof if working with sequences
  - Large overhead if working with multisets

Multiset-Oriented Rules

- Rules can talk about multisets
- Rules can have multisets of premises
- Specified by **parametric multiset comprehension**

$$\frac{\{\ e_i \ \mathrm{val}\ \}}{\{e_i \ @\ \mathrm{w}_i\}\ \mathrm{final}}\ (i \in I)$$

Linear Destination Passing Style

- "Branching" stack machine with explicit return addresses
  - $(e)^d$ – evaluate e for d
  - $(v)_d$ – return v to d
  - $(\text{call } d_1 \text{ with } d_2)^d$ – wait for results

$$\frac{}{(\text{hold } e)^d \Rightarrow_w (\text{hold } e)_d} \qquad \frac{}{(\text{resume } e)^d \Rightarrow_w (\text{resume } d')^d, (e)^{d'}}$$

$$\frac{}{(\text{resume } d')^d, (\text{hold } e)_{d'} \Rightarrow_w (e)^d}$$

LDP rules for `call`

$$\frac{}{(\text{call } e_1 \text{ with } e_2)^d \Rightarrow_{\text{w}} (\text{call } d' \text{ with } d'')^d, (e_1)^{d'}, (e_2)^{d''}}$$

$$\frac{\text{w}'/u = x{:}\tau.\, e \in \Delta}{\begin{array}{l}(\text{call } d' \text{ with } d'')^d, (\text{w}'/u)_{d'}, (v)_{d''} \Rightarrow_{\text{w}} (\text{expect } d''' \text{ from w}')^d \\ \qquad\qquad\qquad\qquad\qquad\qquad\qquad \cdot \Rightarrow_{\text{w}'} ([v/x]e)^{d'''}\end{array}}$$

$$\frac{v' \text{ val}}{\begin{array}{l}(\text{expect } d''' \text{ from w}')^d \Rightarrow_{\text{w}} (v')_d \\ \qquad\qquad (v')^{d'''} \Rightarrow_{\text{w}'} \cdot\end{array}}$$

Orchestration

Simplified for typesetting reasons

- Evaluation

$$\frac{\{\ \Delta;\ e_i \Rightarrow_{w_i} (\Delta, \Delta_i);\ e_i'\ \}}{\Delta; \{e_i\ @\ w_i\}, E \Rightarrow (\Delta, \{\Delta_i\}); \{e_i'@\ w_i\}, E}\ (i \in I)$$

- Typing

$$\frac{\{\ \Sigma;\ d_i{:}\tau_i \mid\!-_{w_i} e_i\ \} \qquad \Sigma \mid\!- \Delta}{\Sigma; \{d_i : \tau_i\} \mid\!- \Delta; \{e_i\ @\ w_i\}}\ (i \in I)$$

Substructural meta-theory

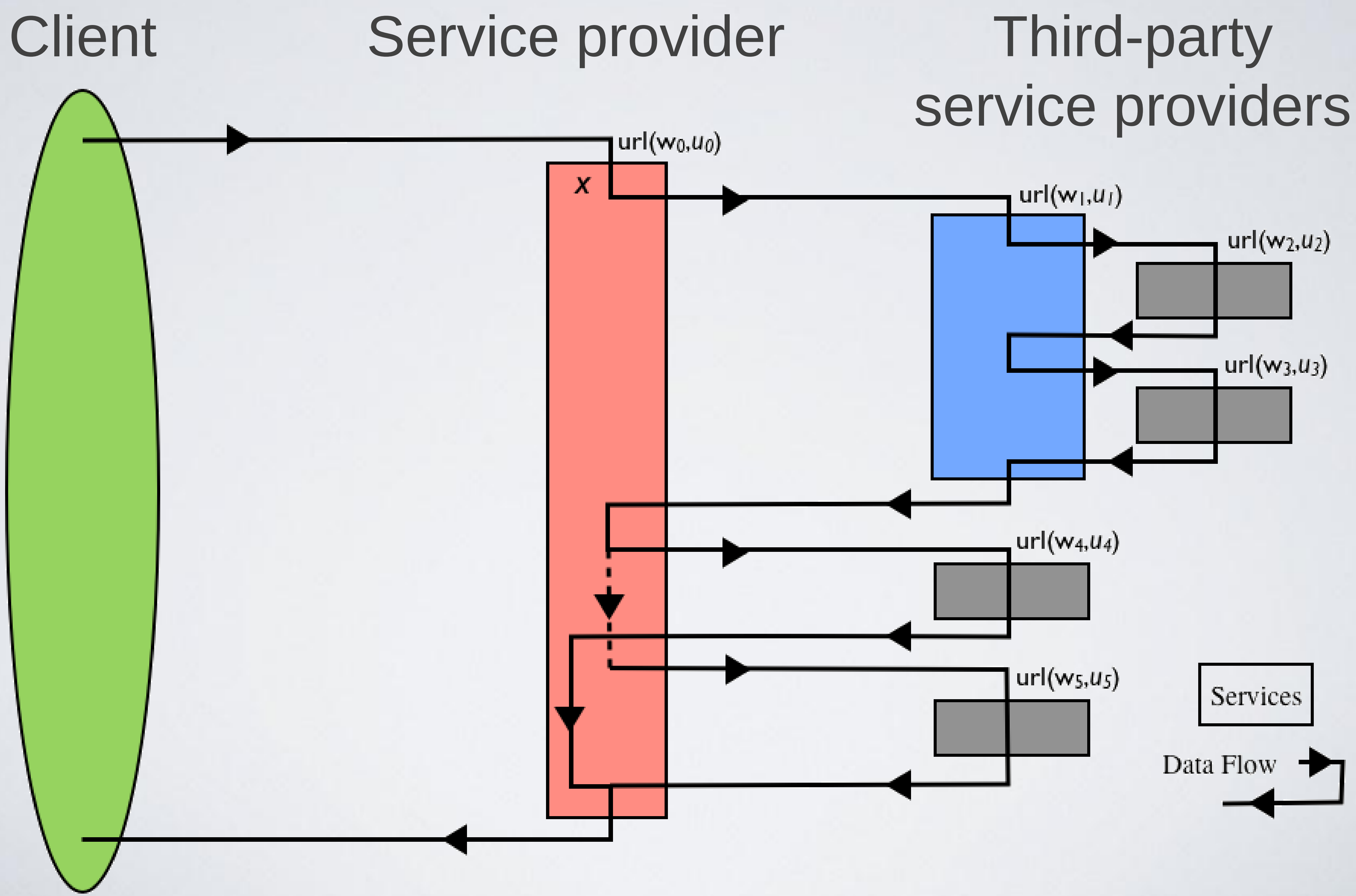
	Type Preservation	**Progress**
Local	If $\Sigma; d{:}\tau \vdash_w e$ and $\Sigma \vdash \Delta$ and $\Delta; e \Rightarrow_w \Delta'; e'$, then $\Sigma'; d{:}\tau \vdash_w e'$ and $\Sigma' \vdash \Delta'$	If $\Sigma; d{:}\tau \vdash_w e$ and $\Sigma \vdash \Delta$, then • either e val • or $\Delta; e \Rightarrow_w \Delta'; e'$
Global	If $\Sigma; \Lambda \vdash \Delta; E$ and $\Delta; E \Rightarrow \Delta'; E'$, then $\Sigma'; \Lambda \vdash_w \Delta'; e'$	If $\Sigma; \Lambda \vdash \Delta; E$, then • either E final • or $\Delta; E \Rightarrow \Delta'; E'$

Managing Data Flow on the Web

Services [use other services]*

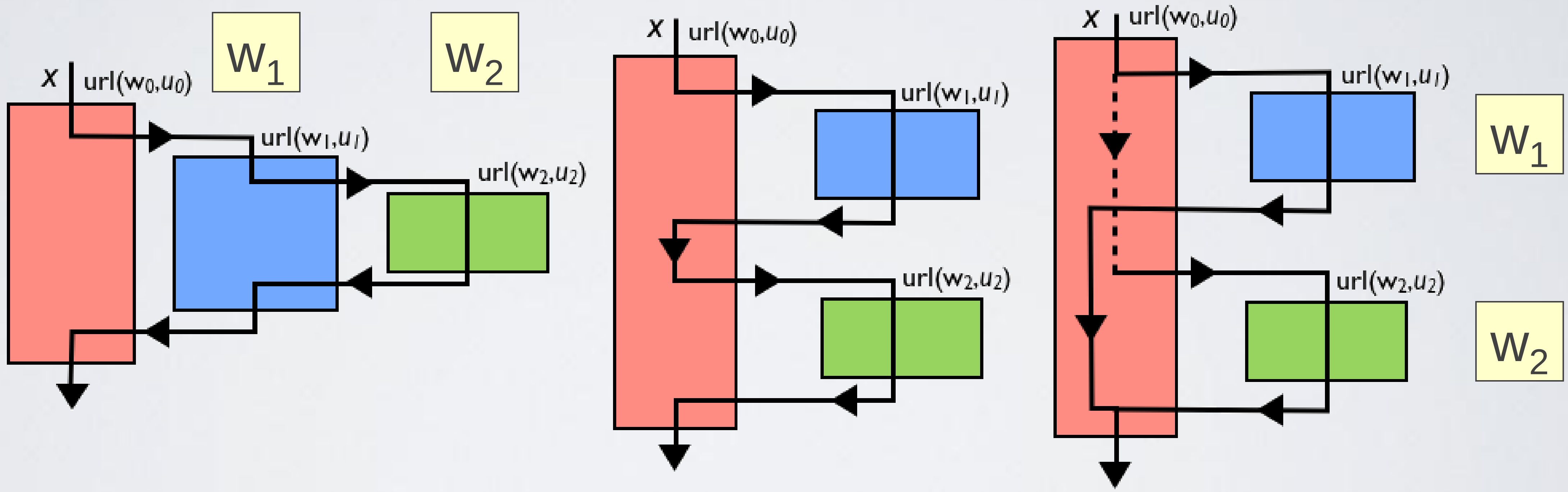
- How does a service provider describe data paths through the web?
- How can a client control where her data goes?

Scenario

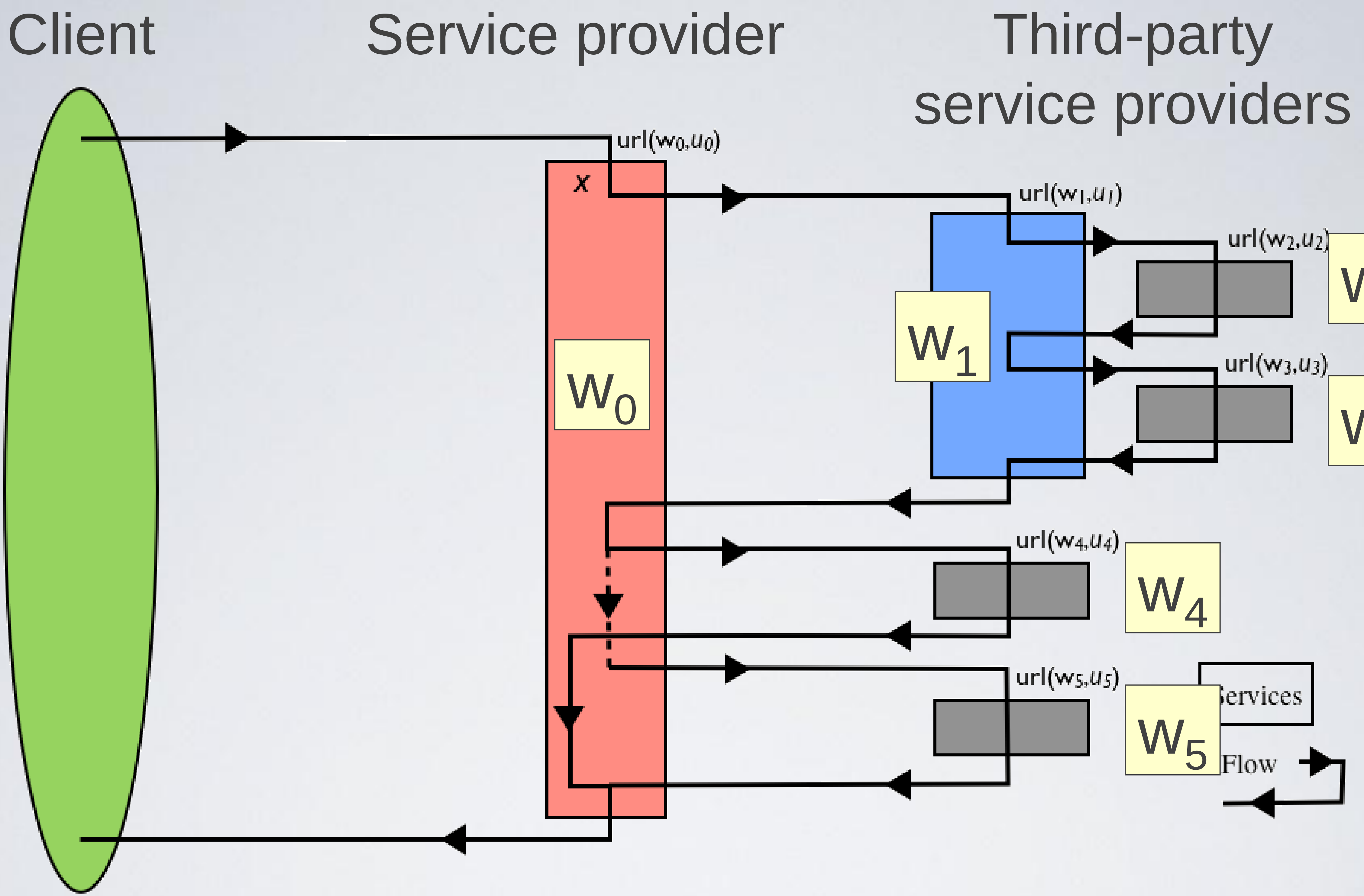

Client
Service provider
Third-party
service providers
url(w_0,u_0)
x
url(w_1,u_1)
url(w_2,u_2)
url(w_3,u_3)
url(w_4,u_4)
url(w_5,u_5)
Services
Data Flow

Describing data paths

$$\mu \ ::= \ \bullet \ \mid \ w; \mu \ \mid \ \mu \text{ o } \mu' \ \mid \ \mu \parallel \mu'$$



$w_1; w_2$ $\qquad$ $w_1 \text{ o } w_2$ $\qquad$ $w_1 \parallel w_2$



w_0 ;(w_1 ; (w_2 o w_3)) o (w_4 || w_5)

Describing flow policies

$$
\begin{aligned}
\rho \ ::= \ & T \mid F \mid \neg\rho \mid \rho \wedge \rho' \mid \rho \vee \rho' \\
& \mid \bullet \mid w;\rho \mid \rho \circ \rho' \\
& \mid \{w_i\}^*;\rho \mid \{w_i\}?;\rho \\
& \mid (\rho)^* \circ \rho' \mid (\rho)? \circ \rho'
\end{aligned}
$$

➡ Can describe

✓ Basic permissions and prohibitions

✓ Strict sequencing (e.g., anonymization policies)

✓ Flow isolation (a la Chinese wall policy)

Incorporating paths and policies into Qwesst

- Data paths in local and remote function types

➡ τ ::= ... | $\tau[\mu] \rightarrow \tau'$ | $\tau[\mu] \hookrightarrow^{w} \tau'$

✓ Type annotations are inferred

- Policies in call

➡ call e_1 with e_2 [ρ]

Incorporating paths and policies into Qwesst

- Flow inference and control in type checking

$$\frac{\Sigma; \Gamma \vdash_{w} e_1 : \tau[\mu] \hookrightarrow^{w'} \tau' \qquad \Sigma; \Gamma' \vdash_{w} e_2 : \tau \qquad \mu \models \rho}{\Sigma; (\Gamma \parallel (\Gamma' \circ (w'; \mu))) \vdash_{w} \text{call } e_1 \text{ with } e_2 [\rho] : \tau'}$$

- Evaluation remains unchanged

Meta-theory

- The language remains type safe

Perspectives and Future Work

Short Term

- More expressive constructs and data structures
- Features for “real” web development
  - Browser embedded interpreter
  - DOM implementation

✓ We want to build a higher level language that relies on Javascript and markup languages

Longer Term

- More security
- Effects & concurrency
- A way to track and manage dead links
- A logical framework based on multiset comprehension

Thank You

Any Qwesstion?