

# Package ‘itp’

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**Type** Package

**Title** The Interpolate, Truncate, Project (ITP) Root-Finding Algorithm

**Version** 1.2.2

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**Description** Implements the Interpolate, Truncate, Project (ITP) root-finding algorithm developed by Oliveira and Takahashi (2021) <[doi:10.1145/3423597](https://doi.org/10.1145/3423597)>. The user provides the function, from the real numbers to the real numbers, and an interval with the property that the values of the function at its endpoints have different signs. If the function is continuous over this interval then the ITP method estimates the value at which the function is equal to zero. If the function is discontinuous then a point of discontinuity at which the function changes sign may be found. The function can be supplied using either an R function or an external pointer to a C++ function. Tuning parameters of the ITP algorithm can be set by the user. Default values are set based on arguments in Oliveira and Takahashi (2021).

**License** GPL (>= 2)

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**VignetteBuilder** knitr

**URL** <https://paulnorthrop.github.io/itp/>,  
<https://github.com/paulnorthrop/itp>

**BugReports** <https://github.com/paulnorthrop/itp/issues>

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**Author** Paul J. Northrop [aut, cre, cph]

**Maintainer** Paul J. Northrop <p.northrop@ucl.ac.uk>

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i itp-package	<i>itp: The Interpolate, Truncate, Project (ITP) Root-Finding Algorithm</i>
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## Description

Implements the Interpolate, Truncate, Project (ITP) root-finding algorithm developed by Oliveira and Takahashi (2021). The user provides a function, from the real numbers to the real numbers, and an interval with the property that the values of the function at its endpoints have different signs. If the function is continuous over this interval then the ITP method estimates the value at which the function is equal to zero. If the function is discontinuous then a point of discontinuity at which the function changes sign may be found. The function can be supplied using either an R function or an external pointer to a C++ function. Tuning parameters of the ITP algorithm can be set by the user. Default values are set based on arguments in Oliveira and Takahashi (2021).

## Details

The main function is `itp`. See the vignette [Overview of the itp package](#), which can also be accessed using `vignette("itp-vignette", package = "itp")`.

## Author(s)

**Maintainer:** Paul J. Northrop <p.northrop@ucl.ac.uk> [copyright holder]

## References

Oliveira, I. F. D. and Takahashi, R. H. C. (2021). An Enhancement of the Bisection Method Average Performance Preserving Minmax Optimality, *ACM Transactions on Mathematical Software*, **47**(1), 1-24. doi:10.1145/3423597

**See Also**

[itp](#) for the ITP root-finding algorithm

[print.itp](#) and [plot.itp](#) for print and plot methods for objects of class "itp" returned from `itp`.

[xptr\\_create](#) and [xptr\\_eval](#) for creating external pointers to the C++ functions used as examples in this package and evaluating those functions.

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itp

*The ITP root-finding algorithm*


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**Description**

Performs one-dimensional root-finding using the ITP algorithm of Oliveira and Takahashi (2021). The function `itp` searches an interval  $[a, b]$  for a root (i.e., a zero) of the function `f` with respect to its first argument. Each iteration results in a bracketing interval for the root that is narrower than the previous interval. If the function is discontinuous then a point of discontinuity at which the function changes sign may be found.

**Usage**

```
itp(
  f,
  interval,
  ...,
  a = min(interval),
  b = max(interval),
  f.a = f(a, ...),
  f.b = f(b, ...),
  epsilon = 1e-10,
  k1 = 0.2/(b - a),
  k2 = 2,
  n0 = 1
)
```

**Arguments**

<code>f</code>	An R function or an external pointer to a C++ function. For the latter see the article <a href="#">Passing user-supplied C++ functions</a> in the <a href="#">Rcpp Gallery</a> . The function for which the root is sought.
<code>interval</code>	A numeric vector $c(a, b)$ of length 2 containing the end points of the interval to be searched for the root. The function values at the end points must be of opposite signs.
<code>...</code>	Additional arguments to be passed to <code>f</code> .
<code>a, b</code>	An alternative way to set the lower and upper end points of the interval to be searched. The function values at these end points must be of opposite signs.
<code>f.a, f.b</code>	The values of $f(a)$ and $f(b)$ , respectively.

epsilon	A positive numeric scalar. The desired accuracy of the root. The algorithm continues until the width of the bracketing interval for the root is less than or equal to $2 * \text{epsilon}$ .
k1, k2, n0	Numeric scalars. The values of the tuning parameters $\kappa_1, \kappa_2, n_0$ . See <b>Details</b> .

### Details

Page 8 of Oliveira and Takahashi (2021) describes the ITP algorithm and the roles of the tuning parameters  $\kappa_1, \kappa_2$  and  $n_0$ . The algorithm is described using pseudocode. The Wikipedia entry for the [ITP method](#) provides a summary. If the input function  $f$  is continuous over the interval  $[a, b]$  then the value of  $f$  evaluated at the estimated root is (approximately) equal to 0. If  $f$  is discontinuous over the interval  $[a, b]$  then the bracketing interval returned after convergence has the property that the signs of the function  $f$  at the end points of this interval are different and therefore the estimated root may be a point of discontinuity at which the sign of  $f$  changes.

The ITP method requires at most  $n_{\max} = n_{1/2} + n_0$  iterations, where  $n_{1/2}$  is the smallest integer not less than  $\log_2((b - a)/2\epsilon)$ . If  $n_0 = 0$  then the ITP method will require no more iterations than the bisection method. Depending on the function  $f$ , setting a larger value for  $n_0 = 0$ , e.g. the default setting  $n_0 = 1$  used by the `itp` function, may result in a smaller number of iterations.

The default values of the other tuning parameters (`epsilon` =  $1e-10$ , `k1` =  $0.2 / (b - a)$ , `k2` = 2) are set based on arguments made in Oliveira and Takahashi (2021).

### Value

An object (a list) of class "itp" containing the following components:

root	the location of the root, calculated as $(a+b)/2$ , where $[a, b]$ is the bracketing interval after convergence.
f.root	the value of the function evaluated at root.
iter	the number of iterations performed.
a, b	the end points of the bracketing interval $[a, b]$ after convergence.
f.a, f.b	the values of function at $a$ and $b$ after convergence.
estim.prec	an approximate estimated precision for root, equal to the half the width of the final bracket for the root.

If the root occurs at one of the input endpoints  $a$  or  $b$  then `iter` = 0 and `estim.prec` = NA.

The returned object also has the attributes `f` (the input R function or pointer to a C++ function  $f$ ), `f_args` (a list of additional arguments to  $f$  provided in `...`), `f_name` (a function name extracted from `as.character(substitute(f))` or the form of the R function if  $f$  was not named), `used_c` (a logical scalar: FALSE, if  $f$  is an R function and TRUE if  $f$  is a pointer to a C++ function) and `input_a` and `input_b` (the input values of  $a$  and  $b$ ). These attributes are used in `plot.itp` to produce a plot of the function  $f$  over the interval  $(\text{input}_a, \text{input}_b)$ .

### References

Oliveira, I. F. D. and Takahashi, R. H. C. (2021). An Enhancement of the Bisection Method Average Performance Preserving Minmax Optimality, *ACM Transactions on Mathematical Software*, **47**(1), 1-24. doi:10.1145/3423597

**See Also**

[print.itp](#) and [plot.itp](#) for print and plot methods for objects of class "itp" returned from `itp`.

**Examples**

```
#### ----- The example used in the Wikipedia entry for the ITP method

# Supplying an R function
wiki <- function(x) x ^ 3 - x - 2
itp(wiki, c(1, 2), epsilon = 0.0005, k1 = 0.1, n0 = 1)
# The default setting (with k1 = 0.2) wins by 1 iteration
wres <- itp(wiki, c(1, 2), epsilon = 0.0005, n0 = 1)
wres
plot(wres)

# Supplying an external pointer to a C++ function
wiki_ptr <- xptr_create("wiki")
wres_c <- itp(f = wiki_ptr, c(1, 2), epsilon = 0.0005, k1 = 0.1)
wres_c
plot(wres_c)

#### ----- Some examples from Table 1 of Oliveira and Takahashi (2021)

### Well-behaved functions

# Lambert
lambert <- function(x) x * exp(x) - 1
itp(lambert, c(-1, 1))

# Trigonometric 1
# Supplying an R function
trig1 <- function(x, root) tan(x - root)
itp(trig1, c(-1, 1), root = 1 / 10)
# Supplying an external pointer to a C++ function
trig1_ptr <- xptr_create("trig1")
itp(f = trig1_ptr, c(-1, 1), root = 1 / 10)

# Logarithmic
logarithmic <- function(x, shift) log(abs(x - shift))
itp(logarithmic, c(-1, 1), shift = 10 / 9)

# Linear
linear <- function(x) x
# Solution in one iteration
itp(linear, c(-1, 1))
# Solution at an input endpoint
itp(linear, c(-1, 0))

### Ill-behaved functions

## Non-simple zero
```

```

# Polynomial 3
poly3 <- function(x) (x * 1e6 - 1) ^ 3
itp(poly3, c(-1, 1))
# Using n0 = 0 leads to fewer iterations, in this example
poly3 <- function(x) (x * 1e6 - 1) ^ 3
itp(poly3, c(-1, 1), n0 = 0)

## Discontinuous

# Staircase
staircase <- function(x) ceiling(10 * x - 1) + 1 / 2
itp(staircase, c(-1, 1))

## Multiple roots

# Warsaw
warsaw <- function(x) ifelse(x > -1, sin(1 / (x + 1)), -1)
# Function increasing over the interval
itp(warsaw, c(-1, 1))
# Function decreasing over the interval
itp(warsaw, c(-0.85, -0.8))

```

---

itp\_c

*The ITP root-finding algorithm using C++*


---

## Description

Performs one-dimensional root-finding using the ITP algorithm of Oliveira and Takahashi (2021). This function is equivalent to `itp` but calculations are performed entirely using C++, and the arguments differ slightly: `itp_c` has a named required argument `pars` rather than `...` and it does not have the arguments `interval`, `f.a` or `f.b`.

## Usage

```
itp_c(f, pars, a, b, epsilon = 1e-10, k1 = -1, k2 = 2, n0 = 1)
```

## Arguments

<code>f</code>	An external pointer to a C++ function that evaluates the function $f$ .
<code>pars</code>	A list of additional arguments to the function. This may be an empty list.
<code>a, b</code>	Numeric scalars. Lower ( <code>a</code> ) and upper <code>b</code> limits of the interval to be searched for a root.
<code>epsilon</code>	A positive numeric scalar. The desired accuracy of the root. The algorithm continues until the width of the bracketing interval for the root is less than or equal to $2 * \text{epsilon}$ .

$k_1, k_2, n_0$  Numeric scalars. The values of the tuning parameters  $\kappa_1, \kappa_2, n_0$ . See the **Details** section of [itp](#).  
 The default value for  $k_1$  in [itp\\_c](#) is set as the inadmissible value of  $-1$  (in reality  $\kappa_1$  must be positive) as a device to set the same default value for  $k_1$  as [itp](#), that is,  $k_1 = 0.2 / (b - a)$ . If the input value of  $k_1$  is less than or equal to  $0$  then, inside [itp\\_c](#),  $k_1 = 0.2 / (b - a)$  is set.

### Details

For details see [itp](#).

### Value

An object (a list) of class "itp" with the same structure as detailed in the **Value** section of [itp](#), except that the attribute `f_name` is empty (equal to "").

### References

Oliveira, I. F. D. and Takahashi, R. H. C. (2021). An Enhancement of the Bisection Method Average Performance Preserving Minmax Optimality, *ACM Transactions on Mathematical Software*, **47**(1), 1-24. doi:10.1145/3423597

### See Also

[print.itp](#) and [plot.itp](#) for print and plot methods for objects of class "itp" returned from `itp_c` or `itp`.

### Examples

```
wiki_ptr <- xptr_create("wiki")
wres <- itp_c(f = wiki_ptr, pars = list(), a = 1, b = 2, epsilon = 0.0005)
wres
plot(wres, main = "Wiki")
```

---

plot.itp

*Plot method for objects of class "itp"*

---

### Description

Plot method for objects of class "itp" returned from [itp](#).

### Usage

```
## S3 method for class 'itp'
plot(x, ...)
```

**Arguments**

`x`                    An object inheriting from class "itp", a result of a call to `itp`.  
`...`                   Arguments passed to `curve`, such as graphical parameters.

**Details**

Uses `curve` to produce a plot of the function `f` provided to `itp` over the interval within which a root was sought. The estimated root is indicated using a horizontal line drawn at 0 and a vertical line drawn at the estimated root. By default the name of the function `f` is used as a title, but this can be replaced by supplying the argument `main`. The interval over which `f` is plotted can be changed by supplying the arguments `from` and/or `to`.

**Value**

No return value, only the plot is produced.

**See Also**

`itp` for the Interpolate, Truncate, Project (ITP) root finding algorithm.

**Examples**

```
# Lambert

# Supplying an R function
lambert <- function(x) x * exp(x) - 1
x <- itp(lambert, c(-1, 1))
plot(x)

# Supplying an external pointer to a C++ function
lambert_ptr <- xptr_create("lambert")
x <- itp(lambert_ptr, c(-1, 1))
plot(x, main = "Lambert")
```

---

print.itp

*Print method for objects of class "itp"*


---

**Description**

Prints objects of class "itp" returned from `itp`.

**Usage**

```
## S3 method for class 'itp'
print(x, all = FALSE, digits = max(3L, getOption("digits") - 3L), ...)
```

**Arguments**

x	An object inheriting from class "itp", a result of a call to <a href="#">itp</a> .
all	A logical scalar. If all = FALSE then only the estimated root, the value of the function at the root and the number of iterations are printed. If all = TRUE then, in addition, the final bracketing interval [a, b], the values of the function at the end points of this interval and the estimated precision are printed.
digits	The argument digits passed to <a href="#">format</a> to set the number of significant digits to print.
...	Further arguments to be passed to or from other methods. They are ignored in this function..

**Details**

The default setting is to print only the root, the value of the function at the root and the number of iterations. To include the bracketing interval after convergence and the estimated precision use all = TRUE.

**Value**

The argument x is returned, invisibly.

**See Also**

[itp](#) for the Interpolate, Truncate, Project (ITP) root finding algorithm.

---

xptr_create	<i>Create an external pointer to a C++ function</i>
-------------	---

---

**Description**

This function is used in the [itp](#) package to create external pointers to the C++ functions used as examples to illustrate the use of the function [itp](#). These pointers are passed as the argument f to [itp](#). To create their own examples the user will need to create their own C++ function(s) and a function that is similar to xptr\_create.

**Usage**

```
xptr_create(fstr)
```

**Arguments**

fstr	A string indicating the C++ function required.
------	--

**Details**

See the vignette [Overview of the itp package](#) and the file [user\\_fns.cpp](#) for information.

The example C++ functions available in itp are: "wiki", "lambert", "trig1", "poly3", "linear", "warsaw" and staircase.

**Value**

The external pointer.

**See Also**

[xptr\\_eval](#) for calling a C++ function using an external pointer.

**Examples**

```
lambert_ptr <- xptr_create("lambert")
res <- itp(lambert_ptr, c(-1, 1))
```

---

xptr\_eval

*Call a C++ function using an external pointer*

---

**Description**

This function is used in [plot.itp](#) to plot a function and the root estimated by [itp](#).

**Usage**

```
xptr_eval(x, pars, xpsexp)
```

**Arguments**

x	The main argument of the function.
pars	A list of additional arguments to the function. This may be an empty list.
xpsexp	An external pointer to a C++ function.

**Details**

See the [Passing user-supplied C++ functions](#) article in the [Rcpp Gallery](#) for information.

**Value**

A numeric scalar: the value of the C++ function evaluated at the input values x and pars.

**See Also**

[xptr\\_create](#) for creating an external pointer to a C++ function.

**Examples**

```
lambert_ptr <- xptr_create("lambert")
res <- itp(lambert_ptr, c(-1, 1))

# Value at lower limit
xptr_eval(-1, list(), lambert_ptr)

# Value at upper limit
xptr_eval(1, list(), lambert_ptr)

# Value at the estimated root
xptr_eval(res$root, list(), lambert_ptr)
```

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