The Voting Farm
A Distributed Class for Software Voting

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1.   VotingFarmTool.

This document describes a class of C functions implementing a distributed software voting mechanism for EPX [11, 12] or similar message passing multi-threaded environments. Such a tool may be used for example, to set up a restoring organ [9] i.e., an NMR (i.e., N-module redundant) system with N voters.

In order to describe the tool we start defining its basic building block, the *voter*.

A voter is defined as a software module connected to one user module and to a farm of fellow voters arranged into a cliqué.
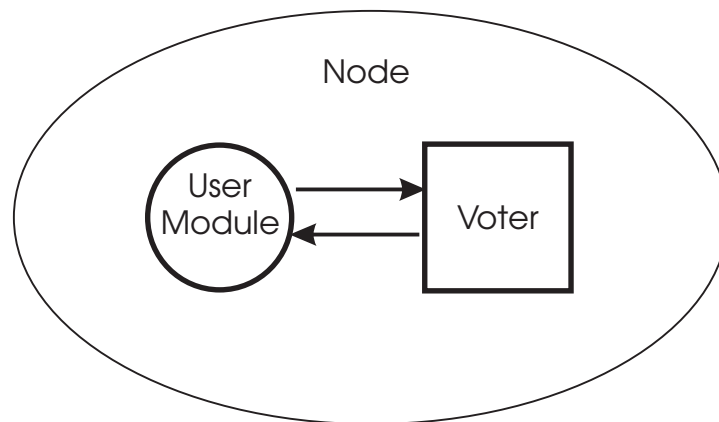

Figure 1. A user module and its local voter.

By means of the functions in the class the user module is able:
- to create a static "picture" of the voting farm, needed for the set up of the cliqué;
- to instantiate the local voter;
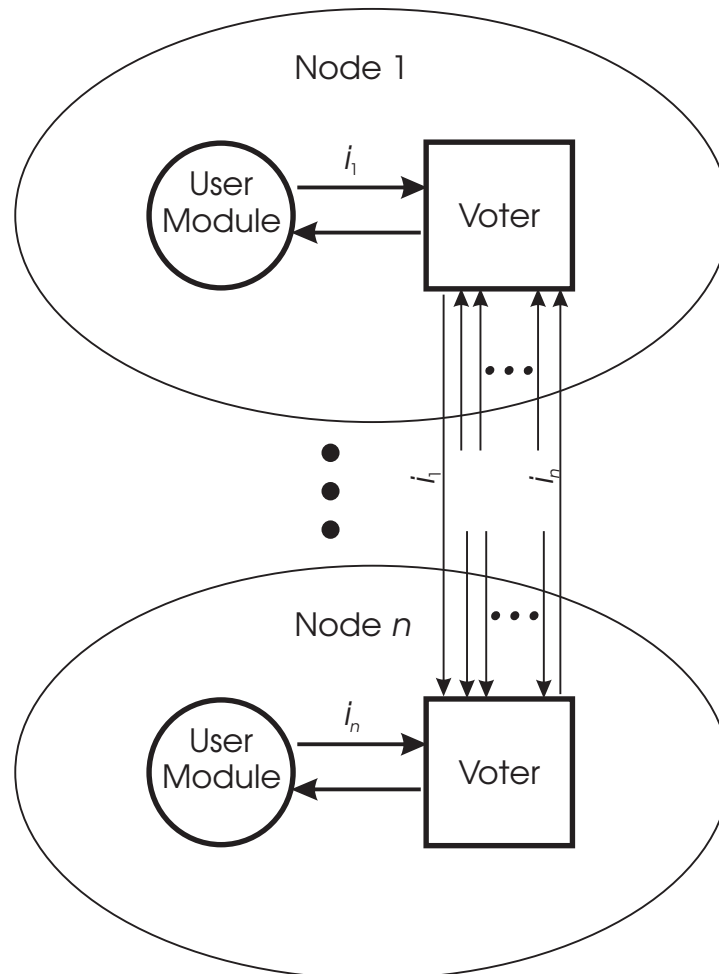- to send input or control messages to that voter.

Figure 2. The architecture of the voting farm: each user module connects to one voter and interacts only with it. In particular, the user module sends its local voter only one input value; the voter then broadcasts it across the farm; then it receives $N-1$ messages from its fellows so to be able to perform the voting.

No interlocutor is needed other than the local voter. The other user modules are supposed to create coherent pictures and instances of voters on other nodes of the machine and to manage consistently the task of their local intermediary. All technicalities concerning the set up of the cliqué and the exchange of messages between the voters are completely transparent to the user module. More information about the voting farm may be found in [6, 7, 8].

In the following the basic functionalities of the VotingFarm class will be discussed, namely how to set up a "passive farm", or a non-alive (in the sense of [4, 5]) topological representation of a yet-to-be-activated voting farm; how to initiate the voting farm; how to control the farm.

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2.   Prologue: headers, global variables, etc.

#define `VF_MAX_NTS` 16   /∗ size of stacks ≡ max value for N ∗/
#define `VOTING_FARMS_MAX` 64   /∗ max number of simultaneous active voting farms ∗/
#define `VF_MAX_INPUT_MSG` 512   /∗ max size of an input message ∗/
#define `VF_MAX_MSGS` 10   /∗ max size of the message buffer ∗/
#define `VF_EVENT_TIMEOUT` 10   /∗ *Select* time-out is 10 seconds ∗/
#define `NO` 0
#define `YES` 1

#define `E_VF_OVERFLOW` −1   /∗ error conditions ∗/
#define `E_VF_CANT_ALLOC` −2
#define `E_VF_UNDEFINED_VF` −3
#define `E_VF_WRONG_NODE` −4
#define `E_VF_GETGLOBID` −5
#define `E_VF_CANT_SPAWN` −6   /∗ *CreateThread* error ∗/
#define `E_VF_CANT_CONNECT` −7   /∗ *ConnectLink* error ∗/
#define `E_VF_RECVLINK` −8   /∗ *RecvLink* error ∗/
#define `E_VF_BROADCAST` −9   /∗ Invalid input message - can't broadcast ∗/
#define `E_VF_DELIVER` −10   /∗ Invalid output **LinkCB_t** - can't deliver ∗/
#define `E_VF_BUSY_SLOT` −11   /∗ Duplicated input message ∗/
#define `E_VF_WRONG_VFID` −12
#define `E_VF_WRONG_DISTANCE` −13
#define `E_VF_INVALID_VF` −14
#define `E_VF_NO_LVOTER` −15   /∗ exactly one voter is mandatorily needed ∗/
#define `E_VF_TOO_MANY_LVOTERS` −16   /∗ exactly one voter is mandatorily needed ∗/
#define `E_VF_WRONG_MSG_NB` −17   /∗ wrong number of messages ∗/
#define `E_VF_SENDLINK` −18   /∗ *SendLink* error ∗/
#define `E_VF_INPUT_SIZE` −19   /∗ inconsistency in the size of the input ∗/
#define `E_VF_UNDESCRIBED` −20   /∗ undescribed *vf* object ∗/
#define `E_VF_INACTIVE` −21   /∗ inactive *vf* object ∗/
#define `E_VF_UNKNOWN_SENDER` −22   /∗ inconsistency—sender unknown ∗/
#define `E_VF_EVENT_TIMEOUT` −23   /∗ a *Select* reached time-out ∗/
#define `E_VF_SELECT` −24   /∗ a *Select* returned an index out of range ∗/
#define `E_VF_WRONG_ALGID` −25   /∗ AlgorithmID out of range ∗/
#define `E_VF_NULLPTR` −26   /∗ A pointer parameter held Λ ∗/
#define `E_VF_TOO_MANY` −27   /∗ Too many opened voting farms ∗/

#define `VF_ERROR_NB` 28   /∗ number of errors, plus one ∗/
#define `VF_MAX_FARMS` 64   /∗ maximum number of farms available ∗/   /∗ voting algorithms ∗/
#define `VFA_EXACT_CONCENSUS` 0
#define `VFA_MAJORITY` 1
#define `VFA_MEDIAN` 2
#define `VFA_PLURALITY` 3
#define `VFA_WEIGHTED_AVG` 4
#define `VFA_SIMPLE_MAJORITY` 5
#define `VFA_SIMPLE_AVERAGE` 6
#define `VF_SUCCESS` 1
#define `VF_FAILURE` 0

#define `VF_NB_ALGS` 7   /∗ nb of algorithms plus one ∗/
        /∗ default value for the ϵ threshold of formalized majority voting ∗/
#define `VFD_EPSILON` $5 \cdot 10^{-5}$

#define `VFP_INITIALISING` 0
#define `VFP_CONNECTING` 1

```
#define VFP_BROADCASTING 2
#define VFP_VOTING 3
#define VFP_WAITING 4
#define VFP_FAILED 5
#define VFP_QUITTING 6
```

3.   Two global variables have been supplied for the user to quer1y the error status of the application and the name of the function which experienced the error. Their definition constitutes the main part of the following section.

⟨ Global Variables and # **include**'s 3 ⟩ ≡

#**include** `<stdio.h>`
#**include** `<stdlib.h>`
#**include** `<stdarg.h>`
#**include** `<sys/root.h>`
#**include** `<sys/logerror.h>`
#**include** `<sys/link.h>`
#**include** `<sys/select.h>`
#**include** `<sys/time.h>`
#**include** `<sys/thread.h>`
#**ifdef** `SERVERNET`
#**include** `"server.h"`
#**endif**   /∗ SERVERNET ∗/
    int *VF_error*;   /∗ global variable for storing the error condition ∗/
    static double ϵ = `VFD_EPSILON`;
    static double *ScalingFactor* = 1.0;
    int *once* = 1;
    static int *VF_RequestId*(**int**, **int**, **int**);
    typedef struct {
      unsigned char ∗*item*;
      int *item_nr*;
    } **cluster_t**;   /∗ A flag is attached to each object so that the object can be logically "deleted" from the list simply setting its status to `NOT_PRESENT`. Once the list is created, all its elements are labeled as `PRESENT`; as the execution goes by, elements are "logically" removed from the list changing their status to `NOT_PRESENT`. ∗/
    typedef unsigned char flag;
    typedef struct {
      void ∗*object*;
      flag *status*;
    } **value_t**;   /∗ This part has been added in V1.5. It defines a set of (redefineable) symbolic constants representing upper limits for pre-allocated areas used exclusively in the **static** version of the tool. ∗/
#**ifndef** `VF_STATIC_MAX_INP_MSG`
#**define** `VF_STATIC_MAX_INP_MSG` 64
#**endif**
#**ifndef** `VF_STATIC_MAX_LINK_NB`
#**define** `VF_STATIC_MAX_LINK_NB` 16
#**endif**
#**ifndef** `VF_STATIC_MAX_VOTER_INPUTS`
#**define** `VF_STATIC_MAX_VOTER_INPUTS` 20
#**endif**
#**ifdef** `STATIC`
#**define** *AllocationClass* **static**
      LinkCB_t ∗ *st_links*[`VF_STATIC_MAX_LINK_NB`];
      Option_t *st_options*[`VF_STATIC_MAX_LINK_NB`];
      double *st_VFA_sum*;   /∗ used in VFA algorithms ∗/
      double *st_VFA_weight*[`VF_STATIC_MAX_INP_MSG`];
      double *st_VFA_squaredist*[`VF_STATIC_MAX_INP_MSG` ∗ `VF_STATIC_MAX_INP_MSG`];
      cluster_t *st_clusters*[`VF_STATIC_MAX_VOTER_INPUTS`];
      void ∗*st_voter_inputs*[`VF_STATIC_MAX_VOTER_INPUTS`];

```
        char st_chars[VF_STATIC_MAX_VOTER_INPUTS];
        value_t st_VFA_v[VF_STATIC_MAX_INP_MSG];
        char st_voter_inputs_data[VF_STATIC_MAX_VOTER_INPUTS][VF_STATIC_MAX_INP_MSG];
#else
#define AllocationClass
#endif
        unsigned char st_VFA_vote[VF_STATIC_MAX_INP_MSG];
```

This code is used in section 1.

4.   Voting Farm Declaration.   The whole *VotingFarm* class is built upon type **Voting Farm_t**, which plays the same role as the type **FILE** in the standard class of C functions for file management: it offers the user a way to refer to some object from an abstract point of view, masking him/her from all unneeded information concerning its implementation. All a user needs to know is that, in order to use a voting farm, he/she has first to declare an object like follows: **VotingFarm_t** ∗ *vf* ;

The newly defined *vf* variable does not describe any valid voting farm yet; it is simply a pointer with no object attached to it, exactly the same way it goes for a **FILE** ∗*fp* variable which has not been *fopen*'d yet. For that a special function is supplied: *VF_open*, which is discussed in the next subsection.

Each user module which needs to use a voting farm should declare a **VotingFarm_t** ∗ variable.

⟨ Voting Farm Declaration 4 ⟩ ≡
  typedef struct {
    int *vf_id* ;
    int *vf_node_stack* [`VF_MAX_NTS`];
    int *vf_ident_stack* [`VF_MAX_NTS`];

    LinkCB_t ∗ *pipe* [2];

    int *N*;
    int *user_thread* ;
    int *this_voter* ;
    double (∗*distance*)(**void** ∗, **void** ∗);
    flag *broadcast_done* ;
    flag *inp_msg_got* ;
    flag *destroy_requested* ;
#ifdef `SERVERNET`

    RTC_Thread_t rtc ;
#endif
  } **VotingFarm_t**;
  static int *VF_voter* (**VotingFarm_t** ∗);
  int *VF_add* (**VotingFarm_t** ∗, **int**, **int**);
  void *VF_perror* (**void**);
#ifdef `STATIC`
  VotingFarm_t *Table* [`VF_MAX_FARMS`];
#endif
  void ∗*memdup* (**void** ∗*p*, **size_t** *len*)
  {
    void ∗*q* = *malloc* (*len*);
    if (*q*) *memcpy* (*q*, *p*, *len*);
    return *q*;
  }
This code is used in section 1.

5.   In the above, *vf_id* is a unique integer which identifies a voting context, *vf_node_stack* is a stack of node ids (a voter thread will be spawned on each of them), *vf_ident_stack* is a stack of thread id, *N* is a stack pointer (only one stack pointer is needed because the two stacks evolve in parallel), and *user_thread* is the thread id of the caller (or user) module. *pipe* is a couple of pointers to **LinkCB_t**, used to communicate between the user module and the local voter. *this_voter* is the entry of the current voter.

6.   Voting Farm Definition.   A voting farm variable vf can be defined by means of function VF_open e.g., as follows:

> **(1) VotingFarm_t** $*vf$;
> **(2)** $vf = VF\_open(5, distance)$;

After this statement has been executed, an object has been allocated, some initializations have occurred, and the address of the newly created object has been returned into vf. The number the user supplies as the argument of VF_open is an integer which univokely represents the current voting farm and in fact distinguishes it from all other voting farms which possibly will be used at the same times—we may call it a VotingFarm-id. *distance* is an arbitrary metric i.e., a function which gets two pointers to opaque objets, computes a "distance", and returns this value as a positive real number.

Each user module which needs to assemble the same voting farm should actually execute a VF_open statement with the same number as an argument—it is the user's responsibility to do like this. Likewise, coherent behaviour requires that the same metric function is referenced as second parameter of VF_open.

VF_open returns Λ in case of error; otherwise, it returns a pointer to a valid object.

⟨ Voting Farm Definition 6 ⟩ ≡
   VotingFarm_t $*VF\_open($**int** $vf\_id,$ **double** $(*distance)($**void** $*,$ **void** $*))$
   {
#ifdef STATIC
     static int vf_max_farms;
#endif
    AllocationClass
       VotingFarm_t $*vf$;
       static char $*$VFN = "VF_open";
    if $(vf\_id \leq 0)$ {
     $LogError($EC_ERROR, VFN,
       "Illegal␣VotingFarm␣Identifier␣(%d)␣---␣should␣be␣greater␣than␣0.", vf_id);
     $VF\_error =$ E_VF_WRONG_VFID;
     return Λ;
    }
#ifndef STATIC
    if $(($$vf = ($**VotingFarm_t** $*) \; malloc($**sizeof**(**VotingFarm_t**$))) \equiv \Lambda)$ {
     $LogError($EC_ERROR, VFN, "Memory␣Allocation␣Error.");
     $VF\_error =$ E_VF_CANT_ALLOC;
     return Λ;
    }
#else   /$*$ if STATIC is defined, then we fetch the next entry from array '*Table*' $*$/
    if $(vf\_max\_farms <$ VF_MAX_FARMS$)$ $vf = \& Table[vf\_max\_farms{+}{+}]$;
    else {
     $LogError($EC_ERROR, VFN, "Too␣many␣farms.");
     $VF\_error =$ E_VF_TOO_MANY;
     return Λ;
    }
#endif
    if $(distance \equiv \Lambda)$ {
     $LogError($EC_ERROR, VFN, "Invalid␣Metric␣Function␣(NULL).");
     $VF\_error =$ E_VF_WRONG_DISTANCE;
     return Λ;
    }
    $vf{\rightarrow}N = 0$;   /$*$ zero the stack pointer $*$/
    $vf{\rightarrow}vf\_id = vf\_id$;   /$*$ record the vf id $*$/

$vf \rightarrow distance = distance$;   /∗ record the function pointer ∗/
$vf \rightarrow user\_thread = vf \rightarrow this\_voter = -1$;
$LocalLink(vf \rightarrow pipe)$;   /∗ Create a means for communicating with the local voter ∗/
return vf;
}

This code is used in section 1.

7. Voting Farm Description.   Once a **VotingFarm_t** pointer has been created and once an object has been correctly defined and attached to that pointer, the user needs to describe the farm: how many voters are needed, where they should be placed, how to refer to each voter, and so on. This is accomplished by means of function *VF_add*. If the voting farm consists of N voters, then the user shall call *VF_add* N times; each call describes a voter by attaching a couple (n, t) to it, where n is the node of the voter and t is its thread identifier. As an example, the following statements:

> **(1) VotingFarm_t** $*vf$;
> **(2)** $vf = VF\_open(5, distance)$;
> **(3)** $VF\_add(vf, 15, tid1)$;
> **(4)** $VF\_add(vf, 21, tid2)$;
> **(5)** $VF\_add(vf, 4, tid5)$;

declare (line **(1)**), define (line **(2)**), and describe (lines **(3)**–**(5)**) voting farm number 5. A triple of voters has been proposed; voter 0, identified by the couple $(n, t) = (15, tid1)$, voter 1, or couple $(21, tid2)$, and voter 2, or couple $(4, tid5)$.

   Again it is the user's responsibility to operate in a coherent, consistent way during these phases: in this case, he or she needs to declare the farm in exactly the same order, with exactly the same cardinality, with the same attributes on all nodes. Exactly one node-id has to be present and equal to the number of the current node.

   So far no thread has been launched, and no distributed action has taken place—therefore we talk of "passive voting farms" for farms that have been only declared, defined, and described, but not activated yet.

   VF_add returns a negative integer in case of error; otherwise, it returns zero.

⟨ Voting Farm Description 7 ⟩ ≡
  int *VF_add*(**VotingFarm_t** $*vf$, **int** *node*, **int** *identifier*)
  {
    static int *this_node*;   /∗ set function name ∗/
    static char $*$VFN = "VF_add";

    if (*this_node* ≡ 0) *this_node* = GET_ROOT( )→*ProcRoot*→*MyProcID*;

    ⟨ Has *vf* been defined? 8 ⟩
    ⟨ Is *vf* a valid object? 9 ⟩

    vf→*vf_node_stack*[*vf*→*N*] = *node*;
    vf→*vf_ident_stack*[*vf*→*N*] = *identifier*;
    if (*node* ≡ *this_node*)
      if (*vf*→*this_voter* < 0) *vf*→*this_voter* = *vf*→*N*;   /∗ store the current value of the stack pointer ∗/
      else {
        LogError(EC_ERROR, VFN, "There␣must␣be␣only␣one␣local␣voter.");
        return *VF_error* = E_VF_TOO_MANY_LVOTERS;
      }
    vf→*N*++;

    ⟨ Check stacks growth 10 ⟩

    return *VF_error* = 0;
  }
This code is used in section 1.

8.   Checks if *vf* holds a valid (non-Λ) address.

$\langle$ Has *vf* been defined? 8 $\rangle \equiv$
  if (*vf* $\equiv \Lambda$) {
    LogError (EC_ERROR, VFN, "Undefined␣VotingFarm_t␣Object.");
    LogError (EC_ERROR, VFN, "\t(A␣VF_open␣is␣probably␣needed.)");
    return *VF_error* = E_VF_UNDEFINED_VF;
  }

This code is used in sections 7, 11, 24, and 30.

9.   Checks if *vf* points to valid data.

$\langle$ Is *vf* a valid object? 9 $\rangle \equiv$
  if (*vf*→*vf_id* $< 0 \lor$ *vf*→*vf_node_stack* $\equiv \Lambda \lor$ *vf*→*vf_ident_stack* $\equiv \Lambda \lor$ *vf*→*N* < 0) {
    LogError (EC_ERROR, VFN, "Corrupted␣or␣Invalid␣VotingFarm_t␣Object.");
    return *VF_error* = E_VF_INVALID_VF;
  }

This code is used in sections 7 and 30.

10.   Check if a stack overflow event has occurred.

$\langle$ Check stacks growth 10 $\rangle \equiv$
  if (*vf*→*N* $\geq$ VF_MAX_NTS) {
    LogError (EC_ERROR, VFN, "Stack␣Overflow.");
    LogError (EC_ERROR, VFN, "\t(Increase␣the␣value␣of␣VF_MAX_NTS;␣current␣value␣is␣%d.)",
        VF_MAX_NTS);
    return *VF_error* = E_VF_OVERFLOW;
  }

This code is used in section 7.

11.   Voting Farm Activation.   After having described a voting farm, next step is turning that passive description into a "living" (active) object: this is accomplished by means of function *VF_run* which simply spawns the local voter and connects to it. Any inconsistency like e.g., zero or two local voters are managed at this point and results in specific error messages. The one argument **VotingFarm_t** *∗vf* is passed to the newly created thread.

   VF_run returns a negative integer in case of error; otherwise, it returns zero.

⟨ Voting Farm Activation 11 ⟩ ≡
```
  int VF_run(VotingFarm_t ∗vf ){ AllocationClass
          int MyProcID ;
     AllocationClass GlobId_t GlobId ;

     AllocationClass
          int Error ;
#ifdef SERVERNET
          extern LinkCB_t ∗link2server ;
#endif    /∗ set function name ∗/
          static char ∗VFN = "VF_run";

     ⟨ Has vf been defined? 8 ⟩

     ⟨ Has vf been described? 12 ⟩

     if (vf→this_voter < 0) {
        LogError (EC_ERROR, VFN, "No␣voter␣has␣been␣defined␣to␣be␣local.");
        return E_VF_NO_LVOTER;
     }
     MyProcId = GET_ROOT( )→ProcRoot→MyProcID ;      /∗ Get the Global ID structure. ∗/
     if (GetGlobId (& GlobId , Λ) ≡ −1) {
        LogError (EC_ERROR, VFN, "Cannot␣get␣the␣global␣ID␣of␣the␣thread.");
        return E_VF_GETGLOBID;
     }    /∗ for the time being, this field is treated as a flag which tells whether VF_run has been
              executed or not on voting farm vf . Its role will be different when FT_Create_Thread will be
              used instead of CreateThread . ∗/
     vf→user_thread = 0;      /∗ first create a separate thread for the voter function ∗/
#ifdef SERVERNET
     LogError (EC_MESS, VFN, "Creating␣thread␣'VF_voter()'␣via␣RTC_CreateLThread()");
        vf→rtc = RTC_CreateLThread (link2server , vf→vf_ident_stack [vf→this_voter ], DIR_USER_TYPE, Λ,
        0, (RTC_ptr_t) VF_voter , vf , sizeof ( LinkCB_t ∗ ) ) ;
     LogError (EC_MESS, VFN, "RTC_CreateLThread()␣has␣been␣executed.");
#else
     if (CreateThread (Λ, 0, (int(∗)( )) VF_voter , & Error , vf ) ≡ Λ) {
        LogError (EC_ERROR, VFN, "Cannot␣start␣a␣voter␣thread,␣error␣code␣%d.", Error );
        return VF_error = E_VF_CANT_SPAWN;
     }
#endif    /∗ SERVERNET ∗/
     return VF_error = 0; }
```
This code is used in section 1.

12.   This checks whether the farm has been described by means of at least one call to *VF_add*.

⟨ Has *vf* been described? 12 ⟩ ≡
  if (*vf*→*N* < 0) {
    LogError (EC_ERROR, VFN, "Voting␣farm␣%d␣needs␣to␣be␣described.", *vf*→*vf_id*);
    LogError (EC_ERROR, VFN, "\t(You␣probably␣need␣to␣execute␣a␣VF_add␣statement.)");
    return *VF_error* = E_VF_UNDESCRIBED;
  }

This code is used in sections 11 and 24.

13.   This checks whether the farm has been activated by means of a previous call to function *VF_run*.

⟨ Has *vf* been activated? 13 ⟩ ≡
  if (*vf*→*user_thread* < 0) {
    LogError (EC_ERROR, VFN, "Voting␣farm␣%d␣needs␣to␣be␣activated.", *vf*→*vf_id*);
    LogError (EC_ERROR, VFN, "\t(You␣probably␣need␣to␣execute␣a␣VF_run␣statement.)");
    return *VF_error* = E_VF_INACTIVE;
  }

This code is used in section 24.

14.   Voting Farm Control.   All interactions between the user module and the farm go through the *VF_control* and *VF_control_list* functions and objects of **VF_msg_t** type, aka messages.

⟨ Voting Farm Control 14 ⟩ ≡
    ⟨ Type **VF_msg_t** 15 ⟩
    ⟨ Build a **VF_msg_t** message 17 ⟩
    ⟨ Function *VF_control_list* 24 ⟩
    ⟨ Function *VF_control* 26 ⟩
    ⟨ Function *VF_send* 25 ⟩
This code is used in section 1.

15.   A message is an object which holds the information needed for a user module to request a service to a voter and for a voter to respond to a previous user's request. Its definition is simple:

⟨ Type **VF_msg_t** 15 ⟩ ≡
    typedef struct {
        int *code*;
        void *∗msg*;
        int *msglen*;
    } **VF_msg_t**;
This code is used in section 14.

16.   The *code* field specifies the nature of the message (see table (see [table1]) for a complete reference); depending on this, some data may be pointed to by the opaque pointer *msg*. In this case, *msglen* represents the size of that data. This is an example of its usage:

> **(1) VF_msg_t** *message*;
> **(2)** *message.code* = VF_INP_MSG;
> **(3)** *message.msg* = *strdup*(*input*);
> **(4)** *message.msglen* = 1 + *strlen*(*input*);

Note that the voter thread assumes that the user module allocates new memory for each new *message.msg* that is sent to it i.e., *it won't make a personal copy of the area*; on the contrary, it will simply store the pointer and use the pointed storage. Moreover, also deallocation of objects previously defined by the user module will be considered to be managed by this latter.

17.   These functions hide the **VF_msg_t** structure to the user.

⟨ Build a **VF_msg_t** message 17 ⟩ ≡
    ⟨ Input message setup 18 ⟩
    ⟨ Scaling factor message setup 19 ⟩
    ⟨ Message to choose the algorithm 20 ⟩
This code is used in section 14.

18.   Build up an **VF_msg_t** object holding a `VF_INP_MSG` message.

⟨ Input message setup 18 ⟩ ≡
```
VF_msg_t *VFO_Set_Input_Message(void *obj, size_t siz)
{
  static VF_msg_t m;

  if (obj ≡ Λ) {
    VF_error = E_VF_NULLPTR;
    return Λ;
  }
  m.code = VF_INP_MSG;
  m.msg = obj;
  m.msglen = siz;
  return &m;
}
```
This code is used in section 17.

19.   Build up an **VF_msg_t** object holding a `VF_SCALING` message.

⟨ Scaling factor message setup 19 ⟩ ≡
```
VF_msg_t *VFO_Set_Scaling_Factor(double *sf)
{
  static VF_msg_t m;

  m.code = VF_SCALING_FACTOR;
  m.msg = sf;
  m.msglen = sizeof(double);
  return &m;
}
```
This code is used in section 17.

20.   Build up an **VF_msg_t** object holding the chosen algorithm.

⟨ Message to choose the algorithm 20 ⟩ ≡
```
VF_msg_t *VFO_Set_Algorithm(int algorithm)
{
  static VF_msg_t m;

  m.code = VF_SELECT_ALG;
  m.msglen = algorithm;
  return &m;
}
```
This code is used in section 17.

21.   Function *VF_control_list* accepts an array of messages that are transferred across the communication network as one buffer.

Function *VF_control_list* and *VF_control* return a negative integer in case of error; otherwise, they return zero.

22.   List of possible message codes going: from the user module to its local voter (represented as $\mathcal{U} \to \mathcal{L}$), and vice-versa (represented as $\mathcal{U} \to \mathcal{L}$):

- `VF_INP_MSG`: a *msglen*-byte-long input message is stored at the address referenced by the opaque pointer *msg* ($\mathcal{U} \to \mathcal{L}$).
- `VF_OUT_LCB`: the information pointed to by *msg* is the link control block for connecting the local voter to the output module ($\mathcal{U} \to \mathcal{L}$); see Figure 3.
- `VF_SELECT_ALG`: *msg* points to a code which identifies a particular majority voting algorithm out of the set of available algorithms ($\mathcal{U} \to \mathcal{L}$).
- `VF_DESTROY`: a signal meaning that the receiving voter should terminate itself after having freed all no more needed memory ($\mathcal{U} \to \mathcal{L}$).
- `VF_NOP`: No `OP`eration, something like an `ImAlive` signal. For the time being this event is not used.
- `VF_RESET`: on the arrival of this segnal the status is set so to be able to perform a new voting session with the current farm ($\mathcal{U} \to \mathcal{L}$).
- `VF_REFUSED`: certain operations may be refused; for example, if one tries to execute a *VF_close*( ) before a broadcasting operation has been completed, then the voter returns this message to its user module ($\mathcal{L} \to \mathcal{U}$).
- `VF_QUIT`: before quitting, the voter generates a `VF_QUIT` event ($\mathcal{L} \to \mathcal{U}$).
- `VF_DONE`: after broadcasting, a `VF_DONE` event is raised ($\mathcal{L} \to \mathcal{U}$).
- `VF_EPSILON`: An ϵ threshold value needed by the formalized majority voting algorithm ($\mathcal{U} \to \mathcal{L}$).
- `VF_ERROR`: A generic error has occurred ($\mathcal{L} \to \mathcal{U}$).
- `VF_SCALING_FACTOR`: used in the Weighted Averaging Technique (see below) ($\mathcal{U} \to \mathcal{L}$).
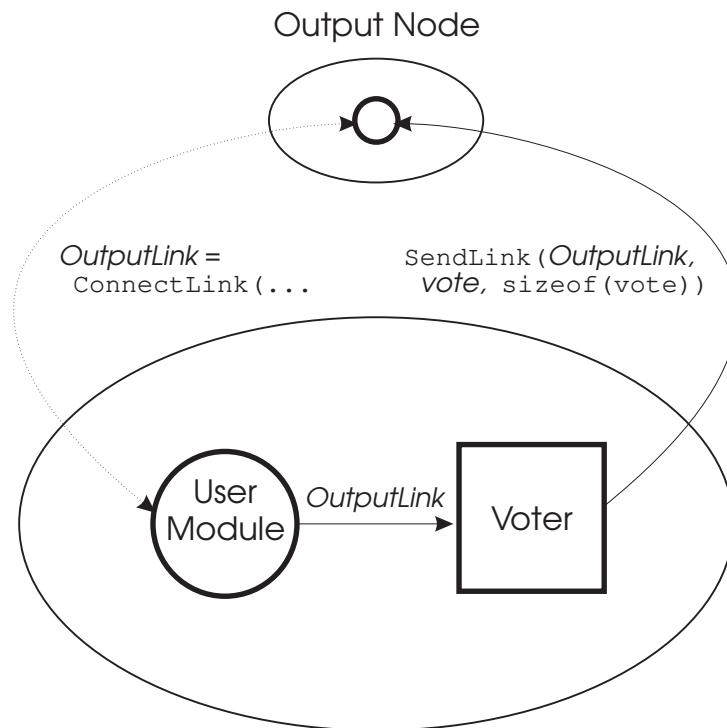
Figure 3. The user module connects to an output module (dashed curve) and then sends to its local voter a `VF_OUT_LCB` message holding the relevant link control. As soon as the voter has performed its voting task, it sends its vote to the output module by means of that link control block.

#**define** `VF_INP_MSG` 100
#**define** `VF_OUT_LCB` 101
#**define** `VF_SELECT_ALG` 102
#**define** `VF_DESTROY` 103
#**define** `VF_NOP` 104

#define `VF_RESET` 105
#define `VF_REFUSED` 106
#define `VF_QUIT` 107
#define `VF_DONE` 108
#define `VF_EPSILON` 109
#define `VF_ERROR` 110
#define `VF_SCALING_FACTOR` 111

23. List of possible message codes going from the local voter to its fellows and vice-versa. They have the same meaning of those defined in the previous section e.g., `VF_V_INP_MSG` is an input message coming from a fellow voter.

#define `VF_V_INP_MSG` 200
#define `VF_V_DESTROY` 203
#define `VF_V_NOP` 204
#define `VF_V_RESET` 205
#define `VF_V_ERROR` 210

24.   This function sends one or more messages to the local voter of voting farm *vf*:

⟨Function *VF_control_list* 24⟩ ≡

  int *VF_control_list*(**VotingFarm_t** ∗*vf*, **VF_msg_t** ∗*msg*, **int** *n*)

  {

    AllocationClass

        int *rv*;   /∗ set function name ∗/

        static char ∗VFN = "VF_control_list";

#ifdef VFDEBUG

    LogError(EC_MESS, VFN, "within␣control_list");

#endif   /∗ VFDEBUG ∗/

    ⟨Has *vf* been defined? 8⟩

    ⟨Has *vf* been described? 12⟩

    ⟨Has *vf* been activated? 13⟩

#ifdef VFDEBUG

    LogError(EC_MESS, VFN, "checked:␣defined,␣described,␣and␣activated");

#endif   /∗ VFDEBUG ∗/

    if $(n < 1 \lor n > \text{VF\_MAX\_MSGS})$ {   /∗ doubt: should it be an error or a warning? ∗/

      LogError(EC_ERROR, VFN, "Wrong␣message␣number␣(%d)␣−−−␣should␣be␣between␣1␣and␣%d.\n",

        n, VF_MAX_MSGS);

      return E_VF_WRONG_MSG_NB;

    }

    if $(vf \rightarrow pipe[0] \neq \Lambda)$ {

#ifdef VFDEBUG

    LogError(EC_MESS, VFN, "Next␣statement␣is␣SendLink(%x,␣%x,␣%d)", *vf*→*pipe*[0], &*msg*[0],

      n ∗ **sizeof** (*msg*[0]));

#endif   /∗ VFDEBUG ∗/

      rv = *SendLink*(*vf*→*pipe*[0], &*msg*[0], *n* ∗ **sizeof** (*msg*[0]));

      if $(rv \neq n * \textbf{sizeof} \ (msg[0]))$ {

        LogError(EC_ERROR, VFN, "Cannot␣send␣the␣message␣to␣local␣voter.");

        return E_VF_SENDLINK;

      }

#ifdef VFDEBUG

    LogError(EC_MESS, VFN, "exiting...");

#endif   /∗ VFDEBUG ∗/

      return *VF_error* = 0;

    }

    LogError(EC_ERROR, VFN, "Corrupted␣or␣Invalid␣VotingFarm_t␣Object.");

    return *VF_error* = E_VF_INVALID_VF;

  }

This code is used in section 14.

25.   To be described...

$\langle$ Function VF_send 25 $\rangle \equiv$
#**define** `VF_MAXARGS` 31
  void $VF\_send($**VotingFarm_t** $*vf$, **int** $argc, \ldots)$
  $\{$
    $AllocationClass$
        va_list ap;
    $AllocationClass$
        VF_msg_t $array[$`VF_MAXARGS`$]$;
    $AllocationClass$
        VF_msg_t $*mp$;
    $AllocationClass$
        int i;
    if $(argc > $`VF_MAXARGS`$)$ $argc = $`VF_MAXARGS`;
    $va\_start(ap, argc)$;
    for $(i = 0;\ i < argc;\ i\mathord{+}\mathord{+})$ $\{$
      $mp = va_arg(ap, $**VF_msg_t** $*)$;
      $memcpy(array + i, mp, $**sizeof**$($**VF_msg_t**$))$;
    $\}$
    $va\_end(ap)$;
    $VF\_control\_list(vf, array, argc)$;
  $\}$
This code is used in section 14.

26.   Simply a shortcut.

$\langle$ Function $VF\_control$ 26 $\rangle \equiv$
  int $VF\_control($**VotingFarm_t** $*vf$, **VF_msg_t** $*msg)$
  $\{$
    return $VF\_control\_list(vf, msg, 1)$;
  $\}$
This code is used in section 14.

27.   Voting Farm Destruction. This is another simple shortcut for sending the `VF_DESTROY` message to a voting farm.

$\langle$ Voting Farm Destruction 27 $\rangle \equiv$
  int $VF\_close($**VotingFarm_t** $*vf)$
  $\{$
    $AllocationClass$
        VF_msg_t msg;
    $AllocationClass$
        int r;
    $msg.code = $`VF_DESTROY`;
    $r = VF\_control(vf, \&msg)$;
    return r;
  $\}$
This code is used in section 1.

28.   to be described.

⟨ Voting Farm Read 28 ⟩ ≡
  VF_msg_t ∗ *VF_get*(**VotingFarm_t** ∗*vf*)
  {
    static VF_msg_t *msg*;
    AllocationClass
       int *recv*, *n*;
    AllocationClass **Option_t***o*[5];   /∗ used to be **Option_t***o*[2] ∗/
    static char ∗VFN = "VF_get";
#**ifdef** VFDEBUG
    LogError(EC_MESS, VFN, "␣vf==%x,␣vf->pipe==%x,␣vf->pipe[0]==%x,␣vf->pipe[1]==%x", *vf*,
       vf⇾*pipe*, *vf*⇾*pipe*[0], *vf*⇾*pipe*[1]);
#**endif**   /∗ VFDEBUG ∗/
    o[0] = *ReceiveOption*(*vf*⇾*pipe*[0]);
    o[1] = *TimeAfterOption*(*TimeNow*( ) + VF_EVENT_TIMEOUT ∗ CLOCK_TICK);

    switch ((*n* = *SelectList*(2, *o*))) {
    case 1: *LogError*(EC_ERROR, VFN, "Timeout␣condition␣reached.");
      LogError(EC_ERROR, VFN,
        "\t(Maybe␣VF_EVENT_TIMEOUT␣should␣be␣enlarged?␣Now␣it's␣%d␣seconds.)",
        VF_EVENT_TIMEOUT);
      msg.*code* = VF_ERROR;
      msg.*msglen* = *VF_error* = E_VF_EVENT_TIMEOUT;
      return &*msg*;
    case 0:
      if ((*recv* = *RecvLink*(*vf*⇾*pipe*[0], (**void** ∗) &*msg*, **sizeof** (*msg*))) ≤ 0) {
        LogError(EC_ERROR, VFN, "Can't␣RecvLink␣[A␣message␣from␣the␣local␣voter]");
        LogError(EC_ERROR, VFN, "\t(return␣code␣is␣%d.)", *recv*);
        msg.*code* = VF_ERROR;
        msg.*msglen* = *VF_error* = E_VF_RECVLINK;
        return &*msg*;
      }
      break;
    default: *LogError*(EC_ERROR, VFN, "Can't␣Select␣−−−␣retvalue␣is␣%d", *n*);
      msg.*code* = VF_ERROR;
      msg.*msglen* = *VF_error* = E_VF_SELECT;
      return &*msg*;
    }   /∗ end **switch** ∗/
#**ifdef** VFDEBUG
    LogError(EC_MESS, VFN, "Received␣a␣message␣(%d␣bytes)␣from␣the␣voter.", *recv*);
#**endif**   /∗ VFDEBUG ∗/
    return &*msg*;
  }
  static int *voter_sendcode*(**LinkCB_t** ∗ *UserLink*, **int** *code*)
  {
    AllocationClass
       int *rv*;
    AllocationClass
       VF_msg_t *msg*;
       static char ∗VFN = "voter_sendcode";
    msg.*code* = *code*;

$rv = SendLink(UserLink, \&msg, \textbf{sizeof}\ (msg));$

$\textbf{if}\ (rv \neq \textbf{sizeof}\ (msg))\ \{$
    $LogError(\texttt{EC\_ERROR}, \texttt{VFN}, \texttt{"Cannot\_send\_the\_message\_to\_the\_user\_module."});$
    $\textbf{return}\ \texttt{E\_VF\_SENDLINK};$
$\}$
$\textbf{return}\ rv;$
$\}$
$\textbf{static int}\ voter\_sendmsg(\textbf{LinkCB\_t} * UserLink, \textbf{VF\_msg\_t} *msg)$
$\{$
    $AllocationClass$
        $\textbf{int}\ rv;$
        $\textbf{static char}\ *\texttt{VFN} = \texttt{"voter\_sendmsg"};$ $/* \textbf{static}\ \text{function} \Rightarrow \texttt{VFN}\ \text{is not touched}\ */$
    $rv = SendLink(UserLink, msg, \textbf{sizeof}\ (*msg));$

    $\textbf{if}\ (rv \neq \textbf{sizeof}\ (*msg))\ \{$
        $LogError(\texttt{EC\_ERROR}, \texttt{VFN}, \texttt{"Cannot\_send\_the\_message\_to\_the\_user\_module."});$
        $\textbf{return}\ \texttt{E\_VF\_SENDLINK};$
    $\}$
    $\textbf{return}\ rv;$
$\}$

This code is used in section 1.

29.   Voting functions are stored into the *DoVoting* array.

⟨ Voting Algorithms 29 ⟩ ≡
  typedef struct {
  unsigned char *vote*;
  int *outcome*;
  } **vote_t**;
  ⟨ Voting Functions 52 ⟩
  typedef void (*$**voter_t**$)(**VotingFarm_t** *, **void** *[], **int**, **vote_t** *);
  static voter_t *DoVoting*[VF_NB_ALGS] = { *VFA_ExactConcensus*,
  VFA_MajorityVoting,
  VFA_MedianVoting,
  VFA_PluralityVoting,
  VFA_WeightedAveraging,
  VFA_SimpleMajorityVoting,
  VFA_SimpleAverage,
  };

This code is used in section 1.

30. The Voter Function.   The function at the basis of the voting thread.

⟨ The Voter Function 30 ⟩ ≡
  static int *VF_voter*(**VotingFarm_t** *∗vf*)
  {
     LinkCB_t ∗ *UserLink*, ∗*OutputLink*, ∗∗*links*;
#ifdef SERVERNET
     LinkCB_t ∗ *serverlink* = *ConnectServer*( );
#endif   /∗ SERVERNET ∗/
     Option_t ∗ *options*;

     int *this_voter*, *this_node*, *N*, *i*, *opt*, *input_nr*;
     VF_msg_t *msg*[VF_MAX_MSGS];
     int *msgnum*;
     VF_msg_t *done*;
     int *Algorithm* = VFA_MAJORITY;
     char *buffer*[VF_MAX_INPUT_MSG + **sizeof**(**int**)];
     int *Error*, *recv*;
     int *input_length*;
     void ∗∗*voter_inputs*;
     unsigned char ∗*vote* = *st_VFA_vote*;
     vote_t *rvote*;
     unsigned int *t0*, *tn*;   /∗ set function name ∗/
     static char ∗VFN = "VF_voter";

     t0 = *TimeNow*( );
#ifdef SERVERNET
     Set_Phase(*serverlink*, VFP_INITIALISING);
#endif
     input_nr = *input_length* = 0;
     UserLink = *OutputLink* = Λ;
     vf→*broadcast_done* = *vf*→*inp_msg_got* = *vf*→*destroy_requested* = NO;
     rvote.*vote* = *vote*;

     ⟨ Has *vf* been defined? 8 ⟩
     ⟨ Is *vf* a valid object? 9 ⟩

     this_voter = *vf*→*this_voter*;
     this_node = *vf*→*vf_node_stack*[*this_voter*];
     if (GET_ROOT( )→*ProcRoot*→*MyProcID* ≠ *this_node*) {
        LogError(EC_ERROR, VFN, "Corrupted␣or␣Invalid␣VotingFarm_t␣Object.");
        return *VF_error* = E_VF_INVALID_VF;
     }
     N = *vf*→*N*;   /∗ Connect to the local Agent ∗/
#ifdef SERVERNET
     ⟨ Ask the Server to set up a connection to an Agent 61 ⟩
#endif   /∗ SERVERNET ∗/
        /∗ Get the (**LinkCB_t** ∗) for communicating with the user module ∗/
     UserLink = *vf*→*pipe*[1];

     ⟨ Create a cliqué 32 ⟩
     ⟨ Poll the user link, the farm links, and the server link 37 ⟩
  }
  ⟨ An example of metric function 31 ⟩
This code is used in section 1.

31.   An example of metric function: a double-returning version of *strcmp*.

⟨ An example of metric function 31 ⟩ ≡
  double *dstrcmp*(**void** ∗*a*, **void** ∗*b*)
  {
    return (**double**) *strcmp*(*a*, *b*);
  }

This code is used in section 30.

32.   A cliqué (fully interconnected crossbar) is set up among the voters. This is done in two "flavours:" in the STATIC one we make use of predefined static data, otherwise we perform *malloc*( )'s.

⟨ Create a cliqué 32 ⟩ ≡
#**ifndef** STATIC
  ⟨ Allocate an array of **LinkCB_t** pointers 33 ⟩
#**else**
  ⟨ Initialize an array of **LinkCB_t** pointers 34 ⟩
#**endif**   /∗ STATIC ∗/
  ⟨ Connect to your *N*-1 fellows 35 ⟩

This code is used in section 30.

33.   An array of Link Control Block Pointers is needed in order to realize the cliqué.

⟨ Allocate an array of **LinkCB_t** pointers 33 ⟩ ≡
  links = (**LinkCB_t** ∗ ∗) *malloc* (*N* ∗ **sizeof** (**LinkCB_t** ∗)) ; *options* = (**Option_t** ∗)
    malloc(($N + 1$) ∗ **sizeof** (**Option_t**));
  voter_inputs = (**void** ∗∗) *calloc*(*N*, **sizeof**(**void** ∗));
  if (*links* ≡ Λ ∨ *options* ≡ Λ ∨ *voter_inputs* ≡ Λ) {
    LogError(EC_ERROR, VFN, "Memory␣Allocation␣Error.");
    return *VF_error* = E_VF_CANT_ALLOC;
  }

This code is used in section 32.

34.   This section is supplied in case the user is willing to use the *static* version of this tool. Rather than allocating memory, we link statically-allocated memory to the appropriate pointers and we initialize them—where needed.

⟨ Initialize an array of **LinkCB_t** pointers 34 ⟩ ≡
  links = *st_links*;
  options = *st_options*;
  voter_inputs = *st_voter_inputs*;
  memset(*voter_inputs*, 0, VF_STATIC_MAX_INP_MSG);

This code is used in section 32.

35. "By the implementation of queues the calling order {to *ConnectLink*} does not matter." [11]. As a consequence, a simple **for** should suffice to create the farm.

N+1 options are "received": N-1 for the cliqué set-up, 1 for connecting to the user module, 1 for connecting to the server; more precisely:

• *options*[*this_voter*] regards the user module;
• *options*[*N*] regards the local server;
• the rest regards the fellow voters.

⟨ Connect to your N-1 fellows 35 ⟩ ≡
#ifdef SERVERNET
  Set_Phase(*serverlink*, VFP_CONNECTING);
#endif
  for (*i* = 0; *i* < *N*; *i*++) {
    if (*i* ≠ *this_voter*) {
      links[*i*] = *ConnectLink*(*vf*→*vf_node_stack*[*i*], *VF_RequestId*(*vf*→*vf_id*, *i*, *this_voter*), &*Error*);
      options[*i*] = *ReceiveOption*(*links*[*i*]);
      if (*links*[*i*] ≡ Λ) {
        LogError(EC_ERROR, VFN, "Cannot␣connect␣to␣voter␣%d.", *i*);
        return *VF_error* = E_VF_CANT_CONNECT;
      }
    }
    else {
      options[*i*] = *ReceiveOption*(*UserLink*);
    }
  }
#ifdef SERVERNET
  options[*N*] = *ReceiveOption*(*serverlink*);
#endif   /∗ SERVERNET ∗/
This code is used in section 32.

36. This function creates a new request id beginning from voting farm id *vfn* and voter id's *v* and *w*.

  static int *VF_RequestId*(**int** *vfn*, **int** *v*, **int** *w*)
  {
    AllocationClass
        int *a*, *b*;
        static int *hundreds* = VF_MAX_NTS ∗ VF_MAX_NTS;
    if (*v* > *w*) *a* = *w*, *b* = *v*;
    else *a* = *v*, *b* = *w*;
    return *hundreds* ∗ (*vfn* + 1) + *a* ∗ VF_MAX_NTS + *b*;
  }

37. If control reaches this section it means that the cliqué has been successfully established between the voters. All future actions depend on the control and input messages of the user; therefore, the voter puts itself into an "endless" loop waiting for new messages to arrive and to be managed. This event-driven loop indeed resembles the one that may be found in any X11 client to manage interactions with the keyboard, the pointer, the display server, and so on.

⟨ Poll the user link, the farm links, and the server link 37 ⟩ ≡   /* t0 = TimeNow(); */
  while (1)
   {
#ifdef SERVERNET
    $opt = SelectList(N + 1, options)$;
#else
    $opt = SelectList(N, options)$;
#endif   /∗ SERVERNET ∗/

    ⟨ A message from the user module 38 ⟩
    else ⟨ A message from the cliqué 43 ⟩
#ifdef SERVERNET
    else ⟨ A message from the server module 46 ⟩
#endif   /∗ SERVERNET ∗/
    else {
      $LogError($EC_ERROR, VFN, "Unknown␣sender\n"$)$;
      return $VF_error = $ E_VF_UNKNOWN_SENDER;
    }
    if $(input\_nr \equiv N \wedge vf{\to}broadcast\_done \equiv$ YES $\wedge\ once)$ {
      FILE $*f$;
      char $fname[80]$;

      $tn = TimeNow()$;
#ifdef TIMESTATS
      $sprintf(fname,$ "overhead.%d"$, this\_voter)$;
      $f = fopen(fname,$ "a+"$)$;
      $fprintf(f,$ "%u␣%u␣%lf\n"$, t0, tn, ($**double**$)(tn - t0)/$CLOCK_TICK$)$;
      $fclose(f)$;
#endif
      $once = 0$;
    }
  }

This code is used in section 30.

38.   If the received options is option # *this_voter*, then a message is coming from the user module.

⟨ A message from the user module 38 ⟩ ≡

  if (*opt* ≡ *this_voter*) {   /∗ Receives the data and checks whether it is an integral multiple of the
        message size or not. In that latter case, an error is issued. ∗/

    if ((*msgnum* = *RecvLink*(*UserLink*, *msg*, VF_MAX_MSGS ∗ **sizeof** (∗*msg*))) % **sizeof** (∗*msg*)) {

      LogError(EC_ERROR, VFN, "Can't␣RecvLink␣[A␣message␣from␣the␣user␣module]");

      LogError(EC_ERROR, VFN, "size␣of␣the␣message␣is␣%d,␣sizeof(*msg)␣is␣%d,␣(1)%(2)␣is␣%d",

        msgnum, **sizeof** (∗*msg*), *msgnum* % **sizeof** (∗*msg*));

      return *VF_error* = E_VF_RECVLINK;

    }

    msgnum /= **sizeof** (∗*msg*);

#ifdef VFDEBUG

    LogError(EC_MESS, VFN, "<voter␣%d>␣Received␣a␣msg␣from␣the␣user␣module␣", *this_node*);

    LogError(EC_MESS, VFN, "(code==%d).␣msgnum==%d.␣Starting␣User␣msg␣management\n",

      msg[0].*code*, *msgnum*);

#endif

    {

      int *i*;

      ⟨ User message management 39 ⟩

    }

  }

This code is used in section 37.

39. A message from the user has been received. Deal with that message. (Note that messages are buffered into the *msg*[ ] array.)

⟨ User message management 39 ⟩ ≡

  for (*i* = 0; *i* < *msgnum*; *i*++) { **void** *∗memdup*(**void** *∗*, **size_t**);

#**ifdef** VFDEBUG

  LogError(EC_MESS, VFN, "<voter␣%d>␣:␣User␣message␣management:␣loop␣%d,␣code==%d\n",
      this_voter, *i*, *msg*[*i*].*code*);

#**endif**

  switch (*msg*[*i*].*code*) {

case VF_INP_MSG:

#**ifdef** VFDEBUG

  LogError(EC_MESS, VFN, "<voter␣%d>␣VF_INP_MSG␣received.\n", *this_node*);

#**endif**

  voter_inputs[*this_voter*] = *memdup*(*msg*[*i*].*msg*, *msg*[*i*].*msglen*);

  input_length = *msg*[*i*].*msglen*;

  input_nr++;   /∗ t0 = TimeNow(); ∗/

#**ifdef** VFDEBUG

  printf("<voter␣%d>␣message␣(as␣a␣double)␣is␣%lf.\n", *this_node*, *∗*((**double** *∗*) *msg*[*i*].*msg*));

#**endif**

  ⟨ Check for a complete message suite; if so, vote, and possibly deliver the outcome 48 ⟩

  vf→inp_msg_got = YES;

  if (*this_voter* ≡ *input_nr* − 1) {

    int *j*;

    ⟨ Broadcast the Input Message 40 ⟩

    vf→broadcast_done = YES;

  }

  break;

  ⟨ case VF_DESTROY: 41 ⟩   /∗ **break**; unneeded, because the statement is unreachable ∗/

  ⟨ case VF_OUT_LCB: 42 ⟩**break**;

case VF_SELECT_ALG: *Algorithm* = *msg*[*i*].*msglen*;

  break;

case VF_SCALING_FACTOR: *ScalingFactor* = *∗*((**double** *∗*) *msg*[*i*].*msg*);

  break;

case VF_EPSILON: *ϵ* = *∗*((**double** *∗*) *msg*[*i*].*msg*);

  break;

case VF_RESET: *input_nr* = *input_length* = 0;

  OutputLink = Λ, *rvote*.*outcome* = *∗vote* = '\0';

  vf→broadcast_done = *vf→inp_msg_got* = *vf→destroy_requested* = NO;

#**ifndef** STATIC

  {

    AllocationClass

        int *i*;

    for (*i* = 0; *i* < *vf→N*; *i*++) {

      free(*voter_inputs*[*i*]);

      voter_inputs[*i*] = Λ;

    }

  }

#**endif**

  break;

case `VF_NOP`:   /∗ for the time being, nothing ∗/
  break;

default: *printf* (`"<voter␣%d>␣:␣default␣case␣in␣switch:␣code==%d\n"`, *this_voter*, *msg*[*i*].*code*);
  break; }   /∗ end **switch** ∗/
  }   /∗ end **for** ∗/
This code is used in section 38.

40.   The actual transmission of this voter's input message to all other voters in the farm. The buffer is
built up so to tie the code of the message and the message itself.

⟨ Broadcast the Input Message 40 ⟩ ≡
  ∗((**int** ∗) *buffer*) = `VF_V_INP_MSG`;
  memcpy (*buffer* + **sizeof** (**int**), *voter_inputs*[*this_voter*], *input_length*);
#**ifdef** `SERVERNET`
  Set_Phase (*serverlink*, `VFP_BROADCASTING`);
#**endif**
#**ifdef** `ZEROPERM`
  for (*j* = 0; *j* < *N*; *j*++) {
    if (*j* ≠ *this_voter*) {
#**ifdef** `VFDEBUG`
      LogError (`EC_MESS`, `VFN`, `"<voter␣%d>␣broadcasting␣(j==%d)\n"`, *this_voter*, *j*);
#**endif**
    if (*input_length* + **sizeof** (**int**) ≠ *SendLink* (*links*[*j*], *buffer*, *input_length* + **sizeof** (**int**))) {
      LogError (`EC_ERROR`, `VFN`, `"Cannot␣SendLink␣to␣voter␣%d."`, *j*);
      return *VF_error* = `E_VF_SENDLINK`;
    }
    }
  }
#**else**
  for (*j* = *this_voter* + 1; *j* < *N*; *j*++) {
    if (*input_length* + **sizeof** (**int**) ≠ *SendLink* (*links*[*j*], *buffer*, *input_length* + **sizeof** (**int**))) {
      LogError (`EC_ERROR`, `VFN`, `"Cannot␣SendLink␣to␣voter␣%d."`, *j*);
      return *VF_error* = `E_VF_SENDLINK`;
    }
  }
  for (*j* = 0; *j* < *this_voter*; *j*++) {
    if (*input_length* + **sizeof** (**int**) ≠ *SendLink* (*links*[*j*], *buffer*, *input_length* + **sizeof** (**int**))) {
      LogError (`EC_ERROR`, `VFN`, `"Cannot␣SendLink␣to␣voter␣%d."`, *j*);
      return *VF_error* = `E_VF_SENDLINK`;
    }
  }
#**endif**
This code is used in sections 39 and 45.

41.   Management of a user message of type `VF_DESTROY`.

⟨ case `VF_DESTROY`: 41 ⟩ ≡
  case `VF_DESTROY`:   /∗ ¡Broadcast a `VF_V_DESTROY` event¿ ?? ∗/
  if ($vf{\rightarrow}broadcast\_done \equiv$ `NO` $\wedge\; vf{\rightarrow}N \neq 1$) {
    $voter\_sendcode$($UserLink$, `VF_REFUSED`);
    break;
  }
  else {
#ifdef `SERVERNET`
  Set_Phase($serverlink$, `VFP_QUITTING`);
#endif
  $voter\_sendcode$($UserLink$, `VF_QUIT`);
#ifdef `SERVERNET`
  { **int** $myident = vf{\rightarrow}vf\_ident\_stack[this\_voter]$; **int error** ;
#ifdef *DoBreakServer*
  if ((**error** = $BreakServer$($serverlink$)) $\neq 0$) $LogError$ (`EC_ERROR`, `VFN`,
    `"BreakServer␣failed,␣error:%d"`, **error**) ;
#endif   /∗ DoBreakServer ∗/
#ifdef `VFDEBUG`
  $LogError$(`EC_MESS`, `VFN`, `"<voter␣%d>␣myident=%d.␣Bye.\n"`, $myident$, $this\_voter$);
#endif
  }
#endif   /∗ SERVERNET ∗/
  $exit$(0);
  return $VF\_error = 0$; }

This code is used in section 39.

42.   Management of a user message of type `VF_OUT_LCB`.

⟨ case `VF_OUT_LCB`: 42 ⟩ ≡
  case `VF_OUT_LCB`: $OutputLink = ($ **LinkCB_t** ∗ $)\; msg[i].msg$;
  if ($OutputLink \neq \Lambda$) {
    if ($rvote.outcome \equiv$ `VF_SUCCESS`) {
      ⟨ Deliver the Outcome 50 ⟩
    }
  }
  else {
    $LogError$(`EC_ERROR`, `VFN`, `"Invalid␣output␣link␣control␣block␣−␣can't␣deliver."`);
  }   /∗ In the event of a `VF_DESTROY` message, the local voter should inform its fellow via the
     broadcasting of a `VF_V_DESTROY` event. ¡Broadcast a `VF_V_DESTROY` event¿= ∗/

This code is used in section 39.

43.   If the received options is not option $\#$ N nor option $\#$ *this_voter*, then a message is coming from a voter in the farm.   Note that this time messages cannot be buffered—only one message at a time will be received. Moreover, messages come from a different memory space—for this reason, the structure of the message can't be that of a **VF_msg_t** object.   A different approach must be used: an integer representing the code message should be directly attached to an opaque area. The resulting buffer constitutes the message.

⟨ A message from the cliqué 43 ⟩ ≡
  if (*opt* ≠ *this_voter* ∧ *opt* ≠ *N*) {
    if ((*recv* = *RecvLink*(*links*[*opt*], *buffer*, VF_MAX_INPUT_MSG)) < 0) {
      LogError(EC_ERROR, VFN, "Can't␣RecvLink␣[A␣message␣from␣the␣clique]");
      LogError(EC_ERROR, VFN, "\t(Sender␣is␣voter␣%d,␣size␣of␣message␣is␣%d.)", *opt*, *recv*);
      return *VF_error* = E_VF_RECVLINK;
    }
    msg[0].*code* = ∗((**int** ∗) *buffer*);
    msg[0].*msg* = *buffer* + **sizeof**(**int**);
    msg[0].*msglen* = *recv* − **sizeof**(**int**);
    ⟨ Cliqué message management 44 ⟩
  }

This code is used in section 37.

44. A new message has come from a voter in the cliqué.

⟨ Cliqué message management 44 ⟩ ≡
  switch (*msg*[0].*code*) {
  case `VF_V_INP_MSG`:
#ifdef `VFDEBUG`
    printf ("voter␣%d␣received␣the␣input␣message␣from␣voter␣%d:␣%lf\n", *this_voter*, *opt*, *((**double**
      *) *msg*[0].*msg*));
#endif
    if (*input_length* ≡ 0) *input_length* = *msg*[0].*msglen*;
    else {
      if (*input_length* ≠ *msg*[0].*msglen*) {
        LogError (`EC_ERROR`, `VFN`, "Wrong␣input␣size");
        return *VF_error* = `E_VF_INPUT_SIZE`;
      }
    }
#ifndef `STATIC`
    if ((*voter_inputs*[*opt*] = (**void** *) *malloc* (*input_length*)) ≡ 0) {
      LogError (`EC_ERROR`, `VFN`, "Memory␣Allocation␣Error.");
      return *VF_error* = `E_VF_CANT_ALLOC`;
    }
#else
    voter_inputs[*opt*] = (**void** *) &*st_voter_inputs_data*[*opt*][0];
#endif
    memcpy (*voter_inputs*[*opt*], *msg*[0].*msg*, *input_length*);
    input_nr ++;

    ⟨ Check for a complete message suite; if so, vote, and possibly deliver the outcome 48 ⟩
    ⟨ Check if it's your turn to broadcast; if so, do it, and take note of that 45 ⟩
    break;
  case `VF_V_DESTROY`:   /* Is there a use for such a message? */   /* for the time being, no action */
#ifdef `VFDEBUG`
    LogError (`EC_MESS`, `VFN`, "voter␣%d␣received␣a␣VF_V_DESTROY␣message␣from␣voter␣%d\n",
      this_voter, *opt*);
#endif
    break;
  case `VF_V_ERROR`:   /* The voter notifies an error condition */   /* for the time being, no action */
    break;
  case `VF_V_RESET`:   /* Is there a use for such a message? */   /* for the time being, no action */
    break;
  case `VF_V_NOP`:   /* for the time being, no action */
    break;
  }   /* end **switch** */

This code is used in section 43.

45.   Broadcasting is performed in an ordered fashion so to prevent deadlocks—a voter is allowed to broadcast only when the following two conditions hold at once:
- it has not performed a broadcast before, and
- the vote-id (a number from 0 to $vf \rightarrow N$-1) is less than or equal to the current number of input messages that have been received (user message included), minus one.

⟨ Check if it's your turn to broadcast; if so, do it, and take note of that 45 ⟩ ≡
      /∗ if (this_voter ¡= input_nr -1) ∗/
   if ($this\_voter \equiv input\_nr - 1$) {
     if ($vf \rightarrow inp\_msg\_got \equiv$ YES $\wedge$ $vf \rightarrow broadcast\_done \equiv$ NO) {
       int j;

       ⟨ Broadcast the Input Message 40 ⟩
       $vf \rightarrow broadcast\_done =$ YES;
     }
   }

This code is used in section 44.

46.   If the received options is option # N, then a message is coming from the local server module.

⟨ A message from the server module 46 ⟩ ≡
   if ($opt \equiv N$) {
     int $recv$;
     char msg[FTB_ELEMENT_SIZE];
     if (($recv = RecvLink(serverlink, ($\textbf{void} *$) msg, FTB_ELEMENT_SIZE)) ≤ 0)
       $LogError$(EC_ERROR, VFN, "couldn't␣receive␣a␣message␣from␣the␣server\n");
     else $LogError$(EC_DEBUG, VFN, "got␣server␣message␣of␣%d␣bytes.\n", $recv$);
     ⟨ Server message management 47 ⟩
   }

This code is used in section 37.

47.   So far, an empty section.

⟨ Server message management 47 ⟩ ≡   /∗ should deal with message kept in msg[], size recv. ∗/
This code is used in section 46.

48.   Every time a new message has come and consequently $input\_nr$ has been incremented, we must check if it's time for voting and if so, after voting, we check if we have an output address

⟨ Check for a complete message suite; if so, vote, and possibly deliver the outcome 48 ⟩ ≡
#**ifdef** VFDEBUG
   $LogError$(EC_MESS, VFN, "<voter␣%d>␣input_nr==%d,␣N==%d\n", $this\_voter$, $input\_nr$, N);
#**endif**
   if ($input\_nr \equiv N$) {
     ⟨ Perform Voting 49 ⟩
     if ($OutputLink \neq \Lambda$) {
       ⟨ Deliver the Outcome 50 ⟩
     }   /∗ input_nr = 0; ∗/
   }

This code is used in sections 39 and 44.

49.   The actual voting algorithm is managed by a function whose address is kept in the *DoVoting* array at
entry no. *Algorithm*.

⟨ Perform Voting 49 ⟩ ≡
  if (*Algorithm* ≥ 0 ∧ *Algorithm* < `VF_NB_ALGS`) {
#ifdef `SERVERNET`
    Set_Phase(*serverlink*, `VFP_VOTING`);
#endif
    DoVoting[*Algorithm*](*vf*, (**void** ∗∗) *voter_inputs*, *input_length*, &*rvote*);
  }
  else {
    LogError(`EC_ERROR`, `VFN`, `"Wrong␣Algorithm␣number:␣%d,␣not␣in␣[0,%d["`, *Algorithm*, `VF_NB_ALGS`);
    return *VF_error* = `E_VF_WRONG_ALGID`;
  }
#ifdef `VFDEBUG`
  if (*rvote.outcome* ≡ `VF_SUCCESS`) {
    LogError(`EC_MESS`, `VFN`, `"<voter␣%d>␣is␣sending␣a␣VF_DONE␣msg␣to␣the␣user−−−vote␣==␣%lf.\n"`,
        this_voter, ∗(**double** ∗) *rvote.vote*);
    printf(`"vote==%lf\n"`, ∗(**double** ∗) *rvote.vote*);
  }
  else *LogError*(`EC_MESS`, `VFN`, `"Vote␣is␣undefined."`);
#endif
  done.code = `VF_DONE`;   /∗ possibly Λ, which means: "no unique vote is available" ∗/
  done.msglen = *rvote.outcome*;
  done.msg = *rvote.vote*;
  recv = *voter_sendmsg*(*UserLink*, &*done*);
#ifdef `VFDEBUG`
  LogError(`EC_MESS`, `VFN`, `"<voter␣%d>␣sent␣a␣VF_DONE␣msg␣(%d␣bytes)␣to␣the␣user.\n"`, *this_voter*,
    recv);
#endif

This code is used in section 48.

50.   The vote is sent to the output module.

⟨ Deliver the Outcome 50 ⟩ ≡
  if (*rvote.outcome* ≡ VF_SUCCESS) {
    if (*input_length* ≠ *SendLink*(*OutputLink*, *vote*, *input_length*)) {
      LogError(EC_ERROR, VFN, "Cannot␣deliver␣the␣output.");
      return *VF_error* = E_VF_DELIVER;
    }
#ifdef SERVERNET
    Set_Phase(*serverlink*, VFP_WAITING);
#endif
  }
  else {
    char *c* = 0;
    if (*SendLink*(*OutputLink*, &*c*, 1) ≠ 1) {
      LogError(EC_ERROR, VFN, "Cannot␣deliver␣the␣negative␣result.");
      return *VF_error* = E_VF_DELIVER;
    }
#ifdef SERVERNET
    Set_Phase(*serverlink*, VFP_FAILED);
#endif
  }

This code is used in sections 42 and 48.

51.   *VF_perror*: the *perror* function of the VotingFarm class. Statically defined as a vector of strings, its entries can be addressed as "−*e*", where *e* is the error condition returned in *VF_error*. The number of messages has been specified so to reduce the risk of inconsistencies.

⟨ Voting Farm Error Function 51 ⟩ ≡

```
static char *errors[VF_ERROR_NB] = {"no error",      /* no error */
"An internal stack has reached its upper limit",      /* E_VF_OVERFLOW */
"The system was not able to execute allocation",      /* E_VF_CANT_ALLOC */
"This operation requires a defined voting farm",      /* E_VF_UNDEFINED_VF */
"A wrong node has been specified",      /* E_VF_WRONG_NODE */
"The system was not able to get the global id",      /* E_VF_GETGLOBID */
"The system was not able to execute CreateThread",      /* E_VF_CANT_SPAWN */
"The system was not able to execute ConnectLink",      /* ConnectLink error */
"The system was not able to execute RecvLink",      /* E_VF_RECVLINK */
"The system was not able to perform broadcasting",      /* E_VF_BROADCAST */
"Invalid output (LinkCB_t*) - can't deliver",      /* E_VF_DELIVER */
"Duplicated input message",      /* E_VF_BUSY_SLOT */
"Invalid voting farm id",      /* E_VF_WRONG_VFID */
"Invalid metric function pointer",      /* E_VF_WRONG_DISTANCE */
"Inconsistent voting farm object",      /* E_VF_INVALID_VF */
"No local voters---one voter has to be specified",      /* E_VF_NO_LVOTER */
"More than one local voter has been specified",      /* E_VF_TOO_MANY_LVOTER */
"A wrong number of messages has been specified",      /* E_VF_WRONG_MSG_NB */
"The system was not able to execute SendLink",      /* E_VF_SENDLINK */
"Inconsistency in the size of the input message",      /* E_VF_INPUT_SIZE */
"This operation requires a described voting farm",      /* E_VF_UNDESCRIBED */
"This operation requires an active voting farm",      /* E_VF_INACTIVE */
"Inconsistency - sender unknown",      /* E_VF_UNKNOWN_SENDER */
"Time-out reached during a Select()",      /* E_VF_EVENT_TIMEOUT */
"A Select() returned an index out of range",      /* E_VF_SELECT */
"Algorithm Id out of range",      /* E_VF_WRONG_ALGID */
"NULL in a call-by-reference pointer",      /* E_VF_NULLPTR */
"Maximun number of opened voting farms exceeded",      /* E_VF_TOO_MANY */
};
```

void *VF_perror*(**void**)
{
  static char *VFN = "VF_perror";

  if (*VF_error*) {
    fprintf(*stderr*, "Error condition number %d raised while in function %s: \"%s\"\n",
      VF_error, VFN, *errors*[− *VF_error*]);
    fflush(*stderr*);
  }
}

This code is used in section 1.

52.   The functions stored in the *DoVoting* array are defined here.

⟨ Voting Functions 52 ⟩ ≡
  ⟨ Exact Concensus 54 ⟩
  ⟨ Majority Voting 55 ⟩
  ⟨ Median Voting 56 ⟩
  ⟨ Plurality Voting 57 ⟩
  ⟨ Weighted Averaging 58 ⟩
  ⟨ Simple Majority Voting 53 ⟩
  ⟨ Simple Average 60 ⟩

This code is used in section 29.

53.   The simplest algorithm, apart from exact concensus—counts the agreement and returns the widest.

⟨ Simple Majority Voting 53 ⟩ ≡
  static void *VFA_SimpleMajorityVoting* (**VotingFarm_t** *∗vf*, **void** *∗inp*[ ], **int** *len*, **vote_t** *∗vote*)
  {
    int *i*, *j*;
    int *n* = *vf*→*N*;
    int *v*[VF_MAX_NTS];
    int *threshold*;

    threshold = *n* ≫ 1;   /∗ n/2; ∗/
    for (*i* = 0; *i* < *n*; *i*++) *v*[*i*] = 0;
    for (*i* = 0; *i* < *n*; *i*++)
      for (*j* = 0; *j* < *n*; *j*++)
        if (*i* ≠ *j*) {
          if (*vf*→*distance* (*inp*[*i*], *inp*[*j*]) < VFD_EPSILON) {
            v[*i*]++;
          }
        }
    for (*i* = 0; *i* < *n*; *i*++)
      if (*v*[*i*] ≥ *threshold*) {
        vote→*outcome* = VF_SUCCESS;
        memcpy (*vote*→*vote*, *inp*[*i*], *len*);
        return;
      }
    vote→*outcome* = VF_FAILURE;
  }

This code is used in section 52.

54.   Exact concensus means perfect, bitwise equality.

⟨ Exact Concensus 54 ⟩ ≡
  static void *VFA_ExactConcensus*(**VotingFarm_t** ∗*vf*, **void** ∗*inp*[ ], **int** *len*, **vote_t** ∗*vote*)
  {
    int *i*;
    int *n* = *vf*→*N*;
    if (*inp*[0] ≡ Λ) {
      vote→*outcome* = VF_FAILURE;
      return;
    }
    for (*i* = 1; *i* < *n*; *i*++) {
      if (*inp*[*i*] ≡ Λ) {
        vote→*outcome* = VF_FAILURE;
        return;
      }
      if (*memcmp*(*inp*[0], *inp*[*i*], *len*) ≠ 0) {
        vote→*outcome* = VF_FAILURE;
        return;
      }
    }
    vote→*outcome* = VF_SUCCESS;
    memcpy(*vote*→*vote*, *inp*[0], *len*);
  }

This code is used in section 52.

55.   Generalized Voters.   Several commonly used voting techniques have been generalized in [10] to "arbitrary N-version systems with arbitrary output types using a metric space framework", including:
- formalized majority voter (**VFA_MAJORITY**; cf. [10, §2.1, pp.445–446]),
- generalized median voter (**VFA_MEDIAN**; cf. [10, §2.2, p.447]),
- formalized plurality voter (**VFA_PLURALITY**; cf. [10, §2.3, pp.447–448]), and the
- weighted averaging technique (**VFA_WEIGHTED_AVG**; cf. [10, §2.4, p.448]).

All these techniques are based on the concept of "metric space" which is now recalled:

A metric space is a couple (X, d), where X is the output space of the voting threads and d is a real value function defined on $X \times X$ which is able in some way to "compare" two objects belonging to X; more precisely, d behaves as a "distance" measure of any two objects in X. More formally, $\forall (x, y, z) \in X^3$ the following properties hold:

1. $d(x, y) \geq 0$ (distances are positive numbers or zeroes);
2. $d(x, y) = 0 \Rightarrow x = y$ (different points have positive distances);
3. $d(x, y) = d(y, x)$ (distances obey the reflexive property);
4. $d(x, z) \leq d(x, y) + d(y, z)$ (two consecutive segments are greater than the segment that straightly connects their loose ends, unless the three points lie on the same straight line;)

then d is called a "metric".

In other words, a metric is a function which is able to compare any two input objects and is able to numerically express a degree of "closeness" between them. [10] shows how four different voting algorithms can be executed starting from such a function. It is the user responsibility to supply a valid metric function on the call to *VF_open*: that function shall get two pointers to opaque objets, compute a "distance", and return that value as a positive real number.

These functions take advantage of the *Stack* class which has been used in order to mimic the list operations in the algorithms in [10].

⟨ Majority Voting 55 ⟩ ≡
```
    static void VFA_MajorityVoting(VotingFarm_t *vf, void *inp[], int len, vote_t *vote)
    {
      int i;
      int n = vf→N;
      int v;
      cluster_t *c;
#ifndef STATIC
      c = calloc(n, sizeof(cluster_t));
#else
      c = st_clusters;
      memset(c, 0, n * sizeof(cluster_t));
#endif
      ⟨ Create a partition of blocks which are maximal with respect to the metric property 59 ⟩
        /* v is set by <Create a partition...> to the cardinality of the partition */
      for (i = 0; i < v; i++) {
        if (c[i].item_nr > n/2) {
          vote→outcome = VF_SUCCESS;
          memcpy(vote→vote, c[i].item, len);
          return;
        }
      }
      vote→outcome = VF_FAILURE;
    }
```
This code is used in section 52.

56.   "Generalized Median Voter", §2.2 of [10, p.447]. See also the "mid-value select" technique in [9, p.60]

#define PRESENT 1
#define NOT_PRESENT 0
⟨ Median Voting 56 ⟩ ≡
  static void *VFA_MedianVoting*(**VotingFarm_t** *∗vf*, **void** *∗inp*[ ], **int** *len*, **vote_t** *∗vote*)
  {
    void *∗inputs*[VF_MAX_NTS];
    value_t *∗v*;
    int *i*, *j*;
    int *ri*, *rj*;
    double *max*, *dist*;
    int *n*, *card*;
#ifndef STATIC
    static char *∗VFN* = "VFA/MedianVoting";
#endif
#ifdef STATIC
    v = *st_VFA_v*;
#else
    v = (**value_t** *∗*) *malloc*(*len* ∗ **sizeof**(**value_t**));
    if (*v* ≡ Λ) {
      LogError(EC_ERROR, VFN, "Memory␣Allocation␣Error.");
      VF_error = E_VF_CANT_ALLOC;
      return;
    }
#endif   /∗ STATIC ∗/
    for (*n* = *vf*→*N*, *i* = 0; *i* < *n*; *i*++) {
    v[*i*].*object* = *inp*[*i*];
    v[*i*].*status* = PRESENT;
    }
    ri = *rj* = 0;
    do {
      for (*card* = *i* = 0, *max* = −1.0; *i* < *n*; *i*++) {
        if (*v*[*i*].*status* ≡ PRESENT) {
          inputs[*card*++] = *v*[*i*].*object*;
          for (*j* = *i* + 1; *j* < *n*; *j*++) {
            if (*v*[*j*].*status* ≡ PRESENT)
              if ((*dist* = (*vf*→*distance*)(*v*[*i*].*object*, *v*[*j*].*object*)) ≥ *max*) {
                max = *dist*;
                ri = *i*;
                rj = *j*;
              }
          }
        }
      }
      if (*max* ≠ −1.0) {
        v[*ri*].*status* = *v*[*rj*].*status* = NOT_PRESENT;
      }
    } **while** (*card* > 2);
    vote→*outcome* = VF_SUCCESS;
    memcpy(*vote*→*vote*, *inputs*[0], *len*);
  }

This code is used in section 52.

57.   "Formalized Plurality Voter", §2.3 of [10, p.447].

⟨ Plurality Voting 57 ⟩ ≡
  static void *VFA_PluralityVoting* (**VotingFarm_t** ∗*vf* , **void** ∗*inp* [ ] , **int** *len* , **vote_t** ∗*vote*)
  {
    int *i* , *j* ;
    int *n* = *vf*→*N* ;
    int *v* ;
    int *max* ;
    cluster_t ∗*c* ;
#**ifndef** STATIC
    c = *calloc* (*n* , **sizeof** (**cluster_t**));
#**else**
    c = *st_clusters* ;
    memset (*c* , 0 , *n* ∗ **sizeof** (**cluster_t**));
#**endif**
    if (*c* ≡ Λ) *LogError* (EC_MESS, "Plurality", "c␣is␣NULL");
    ⟨ Create a partition of blocks which are maximal with respect to the metric property 59 ⟩
#**ifdef** VFDEBUG
    LogError (EC_MESS, "Plurality", "Partition␣has␣been␣created.");
#**endif**
    j = −1;
    for (*max* = *i* = 0; *i* < *v* ; *i*++) {
      if (*c* [*i*] .*item_nr* > *max*) *j* = *i* , *max* = *c* [*i*] .*item_nr* ;
    }
#**ifdef** VFDEBUG
    LogError (EC_MESS, "Plurality", "Max␣computed.");
#**endif**
    if (*max* > 1) {
      vote→*outcome* = VF_SUCCESS;   /∗ memcpy(vote-¿vote, c[i].item, len); ∗/
      memcpy (*vote*→*vote* , *c* [*j*] .*item* , *len*);
    }
    else *vote*→*outcome* = VF_FAILURE;
#**ifndef** STATIC
    free (*c*);
#**endif**
  }

This code is used in section 52.

58.   "Weighted Averaging Technique", §2.4 of [10, p.448]. The *ScalingFactor* variable is used for computing a set of "weights", defined as follows: given n values, $x_1, x_2, \ldots, x_n$, then

$$\forall i \in \{1, 2, \ldots, n\} : w_i = \left[1 + \frac{\prod_{j=1, j \neq i}^{n} \mathbf{d}^2(x_j, x_i)}{a}\right]^{-1}$$

where a is equal to *ScalingFactor* and $\mathbf{d}$ is the metric. Considered $S = \sum_{i=1}^{n} w_i$, the voted value is computed as $x = \left(\frac{\sum_{i=1}^{n} w_i}{S}\right) x_i$ which is of course here computed as $\frac{\sum_{i=1}^{n} w_i x_i}{S}$.

$\langle$ Weighted Averaging 58 $\rangle \equiv$

```
static void VFA_WeightedAveraging(VotingFarm_t *vf, void *inp[], int len, vote_t *vote)
{
    int i, j;
    int n = vf→N;
    double *sum;
    double *weight, wsum;
    double *squaredist;
    double partial, f;
    int r, c;
    static char *VFN = "WeightedAveraging";
#ifdef STATIC
    sum = &st_VFA_sum;
    weight = st_VFA_weight;
    squaredist = st_VFA_squaredist;
#else
    sum = malloc(sizeof(double));
    weight = (double *) malloc(n * sizeof(double));
    squaredist = (double *) malloc(n * n * sizeof(double));
#endif    /* STATIC */
    if (sum ≡ Λ ∨ weight ≡ Λ ∨ squaredist ≡ Λ) {
        LogError(EC_ERROR, VFN, "Memory␣Allocation␣Error.");
        VF_error = E_VF_CANT_ALLOC;
        return;
    }
    if (ScalingFactor ≡ 0) {
        LogError(EC_MESS, VFN, "Illegal␣scaling␣factor␣---␣set␣to␣1");
        ScalingFactor = 1.0;
    }    /* compute the distances */
    for (i = 0; i < n; i++)
        for (j = 0; j < i; j++) {
            f = (vf→distance)(inp[i], inp[j]);
            squaredist[i * n + j] = f * f;
        }
    for (wsum = 0.0, i = 0; i < n; i++) {
        partial = 1.0;
        for (j = 0; j < n ∧ j ≠ i; j++) {
            if (i < j)  r = j, c = i;
            else  r = i, c = j;
            partial *= squaredist[r * n + c];
        }
        partial /= (ScalingFactor * ScalingFactor);
        wsum += weight[i] = 1.0/(1.0 + partial);
```

```
  }
  for (∗sum = 0.0, i = 0;  i < n;  i++) {
    ∗sum += (∗(double ∗) inp[i]) ∗ weight[i];
  }
  if (wsum ≠ 0) {
    ∗sum /= wsum;
    vote⃗outcome = VF_SUCCESS;
    memcpy(vote⃗vote, sum, len);
  }
  else  vote⃗outcome = VF_FAILURE;
#ifndef STATIC
  free(sum);
  free(weight);
  free(squaredist);
#endif
  }
```

This code is used in section 52.

59.   The input values are partitioned into a set of blocks, $V_1, V_2, \ldots, V_n$, such that for each i block V_i is maximal with respect to the property that

$$\forall (x, y) \in V_i \times V_i : \mathbf{d}(x, y) \le \epsilon,$$

where $\mathbf{d}$ is the metric.

In order to reproduce as much as possible the algorithmic formalism of [10] we decided
- to mimic their Lisp-like statements with stacks, and
- to use **goto** statements.

In this way actions (1)–(6) in [10, p. 445–446] can be (more or less) mapped into the statements corresponding to labels *one* to *six* that follow.

⟨ Create a partition of blocks which are maximal with respect to the metric property 59 ⟩ ≡

```
  {
    char vt;
    char *del;
    void *item;
    int i, j, item_nr;

    vt = GET_ROOT( )→ProcRoot→MyProcID;
#ifndef STATIC
    del = calloc(n, 1);      /* alloc + set all of them to NO */
#else
    del = st_chars;
    memset(del, 0, n);
#endif
    for (v = i = 0; i < n; i++) {
      if (del[i]) continue;
      item = inp[i];
      del[i] = YES;
      c[v].item = item;
      for (item_nr = 1, j = i + 1; j < n; j++) {
        if (¬del[j] ∧ vf→distance(item, inp[j]) < ε) {
          del[j] = YES;
          item_nr++;
        }
      }
      c[v].item_nr = item_nr;
      v++;
    }
#ifndef STATIC
    free(del);
#endif
  }
```

This code is used in sections 55 and 57.

60.   Simple Averaging may be useful e.g., to "melt together" n sample values of a same pixel of an image. Of course it requires the objects are numbers. For the time being, the computation is performed in double precision floating point arithmetics. A problem of this technique is that it assumes the samples are not faulty, in the sense that they do not differ too much from each other: an enormously different addendum would cause the average to differ as well from the "correct" values. The weighted averaging technique is a partial solution to this.

⟨ Simple Average 60 ⟩ ≡
  static void *VFA_SimpleAverage* (**VotingFarm_t** *∗vf*, **void** *∗inp* [ ], **int** *len*, **vote_t** *∗vote*)
  {
    int *i*;
    int *n = vf→N*;
    double *∗sum*;
    static char *∗VFN* = "SimpleAverage";
#ifdef STATIC
    sum = &st_VFA_sum;
#else
    sum = malloc(**sizeof**(**double**));
    if (*sum ≡ Λ*) {
      LogError (EC_ERROR, VFN, "Memory␣Allocation␣Error.");
      VF_error = E_VF_CANT_ALLOC;
      return;
    }
#endif   /∗ STATIC ∗/
    for (*∗sum = 0.0, i = 0*; *i < n*; *i*++) {
      *∗sum += (∗(***double** *∗) inp* [*i*]);
    }
    if (*n ≡ 0*) {
      LogError (EC_ERROR, VFN, "Inconsistency−−−farm␣cardinality␣should␣be␣zero.");
      VF_error = E_VF_INVALID_VF;
      return;
    }
    ∗sum /= n;
    vote→outcome = VF_SUCCESS;
    memcpy (*vote→vote, sum, len*);
#ifndef STATIC
    free (*sum*);
#endif   /∗ STATIC ∗/
  }
This code is used in section 52.

61.   This means:
• send a message to the server telling it "connect me to the Agent (thread id 1)"
• do a *ConnectLink* with the Agent
• send a set up message to the Server so that it propagates that message to the Agent.

⟨ Ask the Server to set up a connection to an Agent 61 ⟩ ≡   /∗ yet to be implemented ∗/
This code is used in section 30.

62. Closings.   This document and source code describes the actual implementation of the Voting Farm Tool as it appears in the EFTOS [1, 2] Basic Functionality Set Library. It has been crafted by means of the `CWEB` system of structured documentation [3].

63.   Index.   Here is a list of the identifiers used, and where they appear. Underlined entries indicate the place of definition. Error messages are also shown.

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⟨Build a **VF_msg_t** message 17⟩   Used in section 14.
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⟨ case `VF_DESTROY`: 41 ⟩   Used in section 39.
⟨ case `VF_OUT_LCB`: 42 ⟩   Used in section 39.

VF

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