

# Quantum Entanglement and Theoretical Modeling

E. Maria Hernandez, T. J. Taylor

California Institute of Technology, Pasadena, USA

**Abstract**—\$ XQLYHUVDO VRIWZDUH SODWIRUP LV

LPSURYLQJWKHGHIFWVLQWKHSUDFWLFDORQH7KLV  
VRIWZDUHSODWIRUPKDV  
GLVWLQFWDGYDQWDJHVLQPRGXODUL]DWLRQLQIRUP  
DWLRQPDQDJPHQWDQG WKH LQWHUIDFHV 6HYHUDO  
WHFKQRORJLHV VXFK DV FRPSXWHU WHFKQRORJ\  
YLUWXDOL]DWLRQ WHFKQRORJ\ QHWZRUN  
WHFKQRORJ\ HWF DUH FRPELQHG WRJHWKHU LQ WKLV  
VRIWZDUH SODWIRUP DQG IRXU ZRUNLQJ PRGHV DUH  
LQWURGXFHG LQ WKLV DUWLFOH LQFOXGLQJ VLQJOH  
PRGH GLVWULEXWHG PRGH  
FORXGPRGHDQGWKHFHQWUDOL]HGPRGH7KHDSSOLFD  
WLRQDUHDRIWKH VRIWZDUH SODWIRUP LV H[WHQG  
WKURXJK WKH VZLWFK EHWZHHQ WKHVH ZRUNLQJ  
PRGHV 7KH VRIWZDUH SODWIRUP FDQ DUUDQJH WKH  
WKHUPDO YDFXXP WHVW SURFHVV DXWRPDWLFDOO\  
7KLV IXQFWLRQ FDQ LPSURYH WKH  
UHOLDELOLW\RIWKHUPDOYDFXXPWHVW

**Keywords**—

6RIWZDUHSODWIRUPWKHUPDOYDFXXPWHVWFRQWUR  
ODQG  
PHDVXUHPHQWZRUNPRGH

,,1752'8&7.21

+(50\$/9DFXXP7HVW797IDFLOLW\LVXVHGWRVLPXOD  
WH

\$ORQJ ZLWK WKH VDWHOOLWH TXDQWLW\  
ERRPLQJ DQG WKH LQVWUXPHQW WHFKQRORJ\  
SURJUHVVVLQJ WKH GDWD DFTXLVLWLRQ  
LQVWUXPHQWV WKH KHDWHU SURJUDPPDEOH  
SRZHU DQG WKH RWKHU KDUGZDUH DUH JURZLQJ  
ERWK LQ TXDQWLW\ DQG WSH 7KVVH GHYHORSLQJ  
QHHGV XSGDWH WKH UHODWHG VRIWZDUH  
1RZGDV GLIIHUHQW LQVWUXPHQW KDUGZDUH  
KDV GLIIHUHQW LQWHUIDFH DQG VRIWZDUH  
SURGXFV 7KH ORFDWLRQ RI WKH LQVWUXPHQWV  
LV  
GHFHQWUDOL]HGWKHUHODWLRQEHWZHHQGLIIHU  
HQWVRIWZDUHSUDWVLV H[FHVVLVYHO\  
FRUHHODWHG WKHQHZ FRQWURO DULWKPHWLF  
FDQQRW EH  
DGGHGHVLODQGWKH797SURFHVVDPDQDJPHQWQ  
HHGVDKDQG  
UHFRUG7KHDERYHVVDWVXVQHGGVLPURYLQJRIWK  
HDSSOLFDWLRQ VRIWZDUH

\$LPLQJ DW WKH VDWXV RI WKH PHDVXUHPHQW  
DQG IOX[ VLPXODWLRQ VXE\VVHP WKH VRIWZDUH  
SODWIRUP IRU 797 LV  
GHYHORSHG7KHUWDLWVRIWKHVRIWZDUHSODWIR  
UPLQFOXGH

б 季 8QLYHUVDO VXLWDELOLW\ IRU GLIIHUHQW  
W\SH LQVWUXPHQWV

=KDQJ/HL=KDQ+DL\DQJDQG\*X0LDRDUHZLWK%HLMLQJ6DWHO  
OLWH,QVWLWXWH  
RI 6SDFHFUDIW (QYLURQPHQW (QLQHULQJSKRQH HPDLO  
IORZVDQG#VLQDFRP

KDUGZDUHDQGGGLIIHUHQWVFDQH

б 0RGXODUL]HGHHVVLQIRUIXQFWLRQPRGLLQJ

季

б &HQWUDOL]HGPDQDJPHQW

季

б /LEUDULHVFDQEHPRGLLHGHDVLO

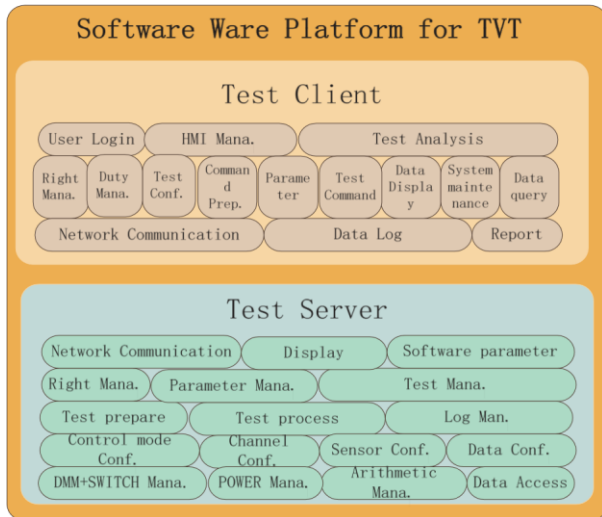
季

б 797SURJUHVVDPDQDJPHQWDXWRPDWDEOH

季

,, :25.,1\*02'(

7KH VRIWZDUH SODWIRUP IRU 797 FRPELQHG  
VHYHUDO WHFKQRORJLHV WRJHWKHU VXFK DV  
FRPSXWHU WHFKQRORJ\  
YLUWXDOL]DWLRQWHFKQRORJ\QHWZRUNWHFKQR  
ORJDQGVRRQ7KH ZKROH SURFHVV RI WKH 797 FDQ  
EH DXWRPDWHG LQFOXGLQJ WHVW  
SUHSDUDWLRQWHVWVUXQQLQJGDWDGLVSOD\DQGW  
KHGDWDDQDOLV  
7KLVVRIWZDUHSODWIRUPKDVIRXUZRUNLQJPRGHV  
VLQJOHPRGH  
GLVWULEXWHGPRGHFORXGPRGHDQGWKHFHQWUD  
OL]HGPRGH7KH  
VLQJOHPRGHLVXVHGLQVPDOORUPLGGOHVLJHRI797I  
DFLOLW\ 'LVWULEXWHG PRGH LV XVHG LQ ODUJH  
VLJH RI 797 IDFLOLW\ 7KH FORXG PRGH LV XVHG LQ  
JLDQW VLJH RI 797 IDFLOLW\ 7KH FHQWUDOL]HG  
PRGH LV XVHG LQ FHQWUDOL]HG FRQWURO RI 797  
IDFLOLWLVH



LJ7KH6WUXFWXUHRIWKH6RIWZDUHSODWIRUPIR  
U797

7KH VRIWZDUH SODWIRUP UHDOLJHG WKH IRXU  
ZRUNLQJ PRGHV  
WKURXJKDVVHPEOLQJDQGGGLVVHPEOLQJWKHPRGX  
OHVLQLWVHOI,W KDV WZR ODUJH PRGXOHV ZKLFK  
DUH 7HVW 6HUYHU76 DQG WKH  
7HVW&OLHQW7&DVVKRZQLQ)LJ7KHWZRPRGXOHVI  
RUP  
WKH&6VWUXFWXUH76PDNHVVHUYHULQ&67&PDNH  
VWKHFOLHQW  
LQ&67KHVHUYHUPRGXOHLVXVHGWRGULYHWKHLQ  
VWUXPHQWVDQG  
FRUWUOKURXJKWKHFRQWURODULWKPHWLF7K  
HFOLHQWLVXVHGWREH WKH KXPdq PDFKLQH  
IQWHUIDFH ZKLFK KDV WKH IXQFWLRQV WR  
SURYLGHWKHLQWHUIDFHWFRQILJXUHWKH797UH  
DGEDFNWKHGDWD  
IHHGWKURXJK767KHIRXUZRUNLQJPRGHVDUHVKRZ  
QLQ)LJ

*A. Single Mode*

7KHVLQJOH PRGH LV XVHG LQVPOO RU PLGGOH  
VLJH RI 797  
IDFLOLW\,WLWVKHPRVWVLPOLILHGDSSHDUDQFHR  
IWKHVRIWZDUH,Q  
WKLVPGRGHWKHGDWDDFTXLVLWLRQFKDQDQHOTXDQ  
WLW\LVQRWELJJHU  
WKDQDQGWKHSURJUDPPDEOHSRZHUFKDQDQHOTXD  
QWLW\LVQRW  
ELJJHUWKDQ7KH76DQGWKH7&DUHLQVWDOOHGLQ  
WKHVDPH  
FRPSXWHU,WLVVKRZQLQ)LJ7KHZKROHZRUNVRI797D  
UH UHDOLJHG LQ WKH VDPH FRPSXWHU LQFOXGLQJ  
WHVW SURFHVV  
PDQDJPHQWQGWKHKDUGZDUHFRQWURO

*B. Distributed Mode*

,QWKHGLVWULEXWHGPRGHGLIIHUHQWIXQFWLRQ  
VDUHDUUDQJHGLQ  
GLIIHUHQWFRPSXWHUV7KHV\QFKURQLJDWLRQRIGL  
IIHUHQWSDUWVLV LQVXUHG E\ WKH QHWZRUN  
7KRXJK WKLVPGRGH RSHUDWRU FDQ  
UHDOLJHVKHPRQLWRURIWKH797IDFLOLW\QORFDO  
RUHPRWH

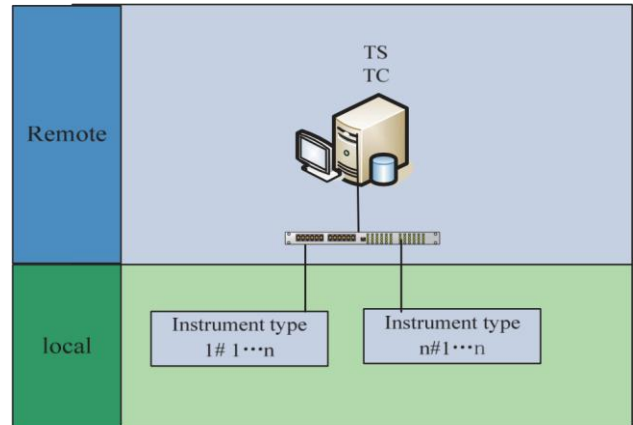


Fig. 2 Single mode

*C. Cloud Mode*

'LVWULEXWHGPRGHLVXVHGLQJLDQWVLJHRI797ID  
FLOLW\Q  
WKLVPGRGHWKHGDWDDFTXLVLWLRQFKDQDQHOTXDQ  
WLW\LVQRWELJJHU  
WKDQDQGWKHSURJUDPPDEOHSRZHUFKDQDQHOTXD  
QWLW\LV QRW ELJJHU WKDQ ,Q WKLVPGRGH PRUH  
VHUYHU DUH  
FRQILJXUHGWRUHDOLJHVKHIXQFWLRQRILQVWUXP  
HQWVGULYLQJ7KH  
QHZZVHUYHUVFRPSXWHUFDQEHDDGGHGLQWRSDUWL  
FLSDWHWKHGXA\ ZKHQ WKH FRPSXWHU GXW\ LV  
WRR KHDYA\ RU DQ H[LVLWQLJ VHUYHUFPSXWHU FDQ  
EH UHPRYHG IRU WKH QHWZRUN ZKHQ WKH  
FRPSXWHGXW\LVOLJKWLQUHDOWLPH7KHQHZZVHUY  
HUFPSXWHU  
VKRXOGLQVWDOO76VRIWZDUH7KHVWUXFWXUHLV  
VKRZQLQ)LJ  
\$OOWKHFOLHQWVVKRXOGEHLQVWDOO7&VRIWZDU  
H,QWKLVPGRGHZRUN  
WKHFOLHQWVFDQEHDDGGHGRUUPRYHGLQUHDOW  
LPHZLWKRXWDQ\ HIIHFW RQ WKH RWKHU SDUWV  
7KH DERYHPHQWLRQHG VHUYHU  
FRPSXWHUDUHQRWOLPLWHGE\WKHORFDWLRQLW  
KHORFDWLRQKDV  
DYDLODEOHQHWZRUN

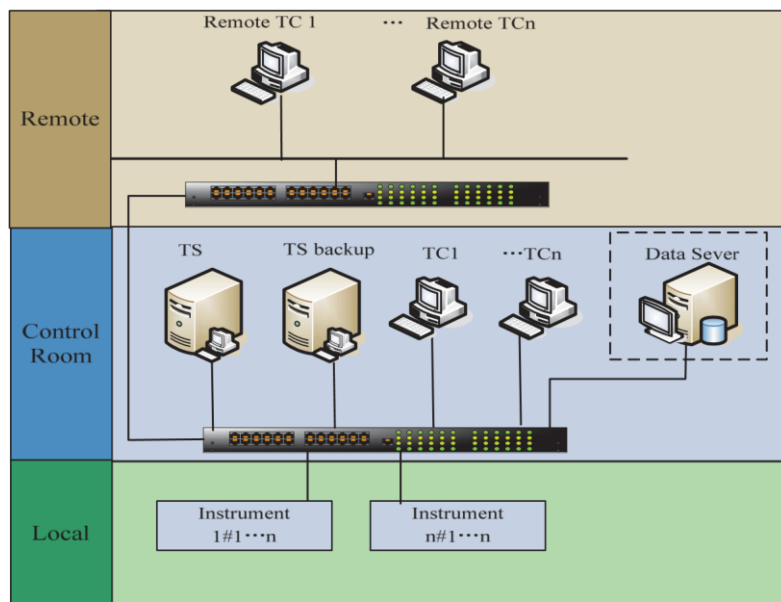
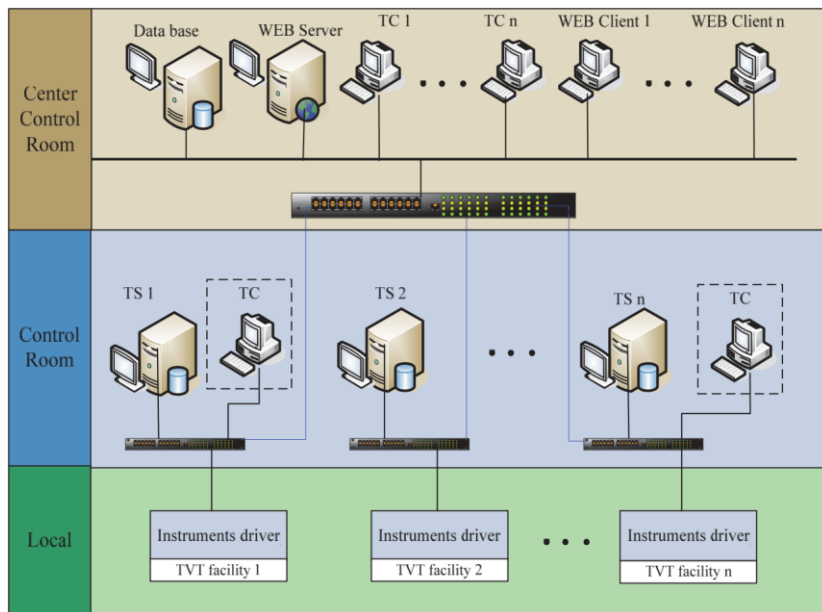


Fig. 3 Distributed mode



)LJ&HQWUDOLJHGPRGH

*D. Centralized Mode*

FRQGLWLRQ,QWKLVPRGHDFHQWHUFRQWUROURRPLVQHHGHGS

7KHFHQWUDOLJHGPRGHLVXVHGLQFHQWUDOLJHGFRQWURORI797  
FHQWHUGDWDEDVHDQZHEVHUYHULVQHHGHGWRR,WLVVKRZQLQ  
IDFLOLWLHV(DFK797IDFLOLW&KDWLVWRVZQVHUYHUV7KHGDWDFDQ )LJ

EHVWRUHGLQHDFKVHUYHURILWVHOIRULQDQRSWLRQ  
DOGDWDEDVH 7KH VHUYHU TXDQWLW\ FDQ EH  
FRVWXPFG E\ WKH ZRUNLQJ

,,,(<7(&+12/2\*,(6

&RPSDUHZLWKWKHH[LVWLQJVRWZDUHWKLVVR  
IWZDUHSODWIRUP  
KDVORWVRIDGYDQWDJHV)RULQVWDQFHWKHVRIW  
ZDUHSODWIRUPLV XVDEOH IRU 797 IDFLQLWLHV  
ORFDWHG IDU DZD\ )RU WKHVH QHZ  
IXQFWLRQVWKHVRIWZDUHSODWIRUPQHGGVVRPH  
NH\WHFKQRORJLHV DQGGHVLJQV

*A. Universal Design*

7KH VRIWZDUH SODWIRUP PDLQO\ IRFXVHV RQ  
LQVWUXPHQWV GULYHQ XQLYHUVDO ZKLFK XVLQJ  
,9,,QWHUFDQJHDEOH 9LUWXDO  
,QVWUXPHQWVWHFKQRORJWREXLOGWKHLQVWU  
XPHQWGULYHQOLEUDU\

*B. Modularity Design*

7KLV VRIWZDUH SODWIRUP GLYLGHV XQLTXH  
IXQFWLRQV LQWR  
PRGXOHVWKURXJKVLP SOLI\LQJWKHLQWUDFWLY  
HLQWHUIDFHVWRNHHS WKH UHODWLYHO\  
LQGHSHQGHHQFH )RU LQVWDQFH GDWD  
DFTXLVLWLRQ LQVWUXPHQW GULYHQ PRGXOH LV  
LQGHSHQGHQW IURP SRZHU  
LQVWUXPHQWVWHFKQRORJWREXLOGWDFXUYHGLVSO  
D\PRGXOHQDQGWKH GDWD DODUP PRGXOH 7KH

IXQFWLRQ PRGXODULW\ WUDLW JLYHV WKH  
VRIWZDUHSODWIRUPPRUHH[WHQGLELOLW\

*C. Multithreading Technology*

7KH VRIWZDUH SODWIRUP DVVLJQV GLIIHUHQW  
WKUHDGV IRU GLIIHUHQW W\SH LQVWUXPHQWV  
GULYHQ RU GLIIHUHQW VHWV RI LQVWUXPHQWV  
%HWZHHQ WKH WKUHDGV WKH UXQQLQJ PRGH LV  
SDUDOOHO WR LQFUHDVH WKH SURFHVV VSHHG  
7KH VHUYHU DSSOLHV  
PXOWLWKUHDGPHWKRGWRFRPPXQLFDWHZLWKWK  
HFOLHQWVWRLQVXUH  
WKHFRPPXQLFDWLRQHILDFE\

*D. Centralization Design*

*E. Distributing Compute*

,Q WKH ODUJH 797 WHVW VLQJOH FRPSXWHU  
FDQQRW ILQLVK WKH LQVWUXPHQWV GULYHQ  
FRQWURO FRPSXWLQJ DQG GDWD FRPPXQLFDWLRQ  
LQ D SHULRG RI WLP 6R WKH GLVWULEXWLQJ  
FRPSXWH LV QHHGHG )RU H[DPSOH WKH  
LQVWUXPHQWV GULYHQ  
IXQFWLRQDQGWKHFRQWUROFRPSXWLQJIXQFWLRQ  
DUHUXQQLQJLQ  
WKH767KH+0,LVUXQQLQJLQWKH7&7KURXJKGLVWU

LEXWLQJ  
WKHZRUNLQJVSHHGRIWKHVRIWZDUHSODWIRUPFD  
QEHLPSURYHG

*F.Instant Access Technology*

,QWKHODUJH797WHVWQHZLQVWUXPHQWVRUFRP  
SXWHUVFDQEH  
DGGHGLQWRWKHWHVWV\VWHPZLWKRXWVWRSSL  
QJWKHWHVWSURFHVVURU  
DQEDGHIHFWRQWKHH[LVWLQJFRQWUROORRSV:L  
WKWKHLQVWDQW  
DFFHVIXQFWRQLQWKHWHVWSURFHVVQHZVHU  
YHUFPSXWHUFDQ  
EHSXWLQWRWKHQHWZRUNWRVKDUHSDUWVRIFRP  
SXWLQJGXWWR  
UHDOL]HWKHFORXGFRPSXWHUIXQFWLRQ

*G.Token Right Technology*

,Q WKL VRIWZDUH SODWIRUP WKH WRNHQ  
ULJKW WHFKQRORJ\ LV  
XVHGWRDWWULEXWHWKHRSHUDWLQJULJKWFRPS  
HWLWLRQIURPVHUYHUV  
WRWKHVDPHLQVWUXPHQW:LWKWKLWVWHFKQRORJ\  
HDFKLQVWUXPHQW  
LVDVVLJQHGWRDXQLTXHWRNHQ7KHVHUYHUZLWK  
WKHFRUUHODWLYH  
WRNHQFDQRSHUDWHWKHLQVWUXPHQW

*H.Interface Customizable*

7KH +0, FDQ EH FXVWRPL]DEOH E\ WKH XVHU ZLWK  
WKH  
DGPLQLVWUDWRUULJKWV

,90\$,1)81&7,21

7KHPDLQIXQFWLRQVRIWKHVRIWZDUHSODWIRUPD  
UHDVIROORZV

9&21&/86,216

7KHVRIWZDUHSODWIRUPIRU797WHVWFDQFRQFO  
XGHDOOWKH  
IXQFWLRQVDERXWWKH797WHVWDQGLVVXLWDEO  
HIRUDQ\VL]HRI WKHUPDO YDFXXP IDFLOLW\ 7KLV  
VRIWZDUH SODWIRUP KDV PRUH GLVWLQFW  
DGYDQWDJHV WKDQ WKH H[LVWLQJ RQH 7KLV  
VRIWZDUH  
SODWIRUPKDVZLGHQ\XVLQJDUHDV

5()5(1&(6

+XDQJ%HQFKHQ0D<RXOLSpacecraft Environment Test Technology.  
%HL-LQJ1DWLRQDO'HHQFH,QGXVWULDO3UHVV  
/LX &KDQJ =KDQ +DL\DJQ :DQJ <X /L 1D \*X 0LDR 37KHUPDO  
YDFXXPWHVWHTXLSPHQVWGDWDPDQDJPHQWSODWIRUPE  
DVHRQGDWDEDVH'  
LQ 6SDFHFUDIW (QYLURQPHQW (QJLQHHULQJ YRO SS 0DU  
)HQJ<DR4L'LDQIX;LH-  
LKXL:DQJ<LURQJ3'HVLJQDQG5HEXLOGLQJ  
RIWKH6SDFHFUDIWWKHUPDOYDFXXP  
WHVWVRIWZDUHV\WHP VWUXFWXUH'LQ  
6SDFHFUDIW(QYLURQPHQW(QJLQHHULQJYROSS0)\  
SSU